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FINAL REPORT

STUDY AND ANALYSIS OF MEDIUM MORTARS

BY

D. D. DUNFEE

T. J. O'DONNELL

OCTOBER 1961

FOR

Watervliet Arsenal, Watervliet, New York
Contract No. DA-30-144-503-ORD-1288
DA Project No. 5W01-13-029
OMS Code No. 5520.12.429

Atlantic Research Corporation
Alexandria, Virginia

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ABSTRACT

The program of test firing for the medium mortars M29 and T227E2 is described. The range facilities, instrumentation and planned statistical test program are also discussed. The data obtained from test groups completed are included and sample firing traces are shown. An analysis of the data is presented in which the recorded phenomena are interpreted and related to potential design and performance parameters and problems.

CONTENTS

INTRODUCTION

During the period from 18 July 1960 to 30 June 1961, Atlantic Research Corporation engaged in a program for the study and analysis of medium mortars under Department of the Army Contract DA-30-144-503-ORD-1288, sponsored by Watervliet Arsenal.

The objectives of this program were to define and study certain parameters in the performance of present medium mortar systems and to analyze these performance parameters so that the data and information obtained might be used to best advantage in the design and development of a new and improved medium mortar system.

TEST PROGRAM

A test program was established based on contract specifications and the information which evolved from subsequent meetings and discussions with Watervliet Arsenal. It was felt that the test program which was finally adopted would permit the maximum utilization of available instrumentation and provide the best basis for correlating data from the various test groups.

The operational specifications and objectives, variables and events of the test program are included in the Appendix for reference.

RANGE FACILITIES

As set forth in the contract specifications, the test firings were to be conducted at one of the artillery ranges at Camp A. P. Hill, Virginia. Authorization for use of the range area was received from Headquarters, Second Army, Fort Meade, Maryland, in the early days of this contract. After a survey of the available range facilities, range 15 was selected as being best suited to the requirements of this program.

The soil common to all the ranges at Camp A. P. Hill readily satisfied the soil requirement for "sandy loam" emplacement of the mortars during some of the test groups.

No soil condition was present on any of the ranges which might be defined as "firm turf". It was therefore, necessary to synthesize the "firm turf" condition. This was accomplished by laying a 45-yd^2 plot of Zoysia grass sod. Zoysia is a wide blade, thickly matted grass sod which readily satisfied the requirement for firm turf emplacement of the mortars during some of the test groups.

A slab of reinforced concrete 20 feet by 20 feet by 12 inches thick was poured at the selected site to satisfy the requirement for "concrete" emplacement of the mortars for the remainder of the test groups. The original plan for emplacement of the mortars on concrete was simply to erect the weapons on the concrete slab and sandbag the baseplate and bipod feet. It was subsequently decided to evaluate the effects of controlled baseplate cant in firings from concrete. In addition, it was decided to seat the baseplate spades and bipod feet in preformed recesses in the concrete to provide controlled factors of cant. This was accomplished by embedding wooden forms in the surface of the concrete slab before the concrete had set up. These forms were configurated to provide suitable recesses which would receive the baseplate spades and provide the proper degree and direction of controlled cant. Subsequent to hardening of the concrete the forms were removed, leaving the preformed seating recesses for the baseplates and bipod feet.

Magazine facilities were provided by erection of a lockable, prefabricated steel building on the site of the ammunition supply point at Camp A. P. Hill.

As originally scheduled, the firing ranges at Camp A. P. Hill were to have been available from 1 August through 30 September 1960. Owing to the late delivery of material from the respective arsenals and delays in completing the instrumentation, preliminary testing of material and instrumentation was initiated on 26 August.

On 14 September communication was received from Camp A. P. Hill that, because of a priority range construction program, authorization for continued use of the range facilities during normal working hours was rescinded and that the range facilities would be, for the most part, available only at night.

It was recognized that the technical and time efficiency losses associated with night field operations without extensive preparations would constitute a severe penalty in the over-all performance of the firing program. A conference was set up between Watervliet Arsenal and this contractor to review this problem area. It was determined that Atlantic Research should take those steps necessary to permit limited night operations and proceed on a best-effort basis until the problem of range availability was resolved.

Several attempts were made to resolve the range availability problem and re-establish a schedule of firing during normal working hours. These efforts were for the most part unsuccessful, and most firings were made at night with supporting lighting and associated equipment that was originally intended to be only a temporary measure. The technical and time efficiency loss associated with these circumstances adversely affected the technical and time efficiency of these field operations.

Setup for the firings is shown in Figure 1.

MOBILE INSTALLATION

Because Camp A. P. Hill is some 75 miles from the home site of Atlantic Research Corporation and because frequent shuttle of the instrumentation between these sites was required for checkout, calibration, and testing, it was necessary that the instrumentation system be completely mobile. A closed van type truck was secured and equipped as a mobile van for the instrumentation system. A 5-kilowatt, gasoline-driven alternating-current generator was installed in the van as the primary alternating-current power source for the instrumentation and associated equipment and for the lighting which was subsequently installed in the van and at the firing site to permit night firing. All of the instrumentation and

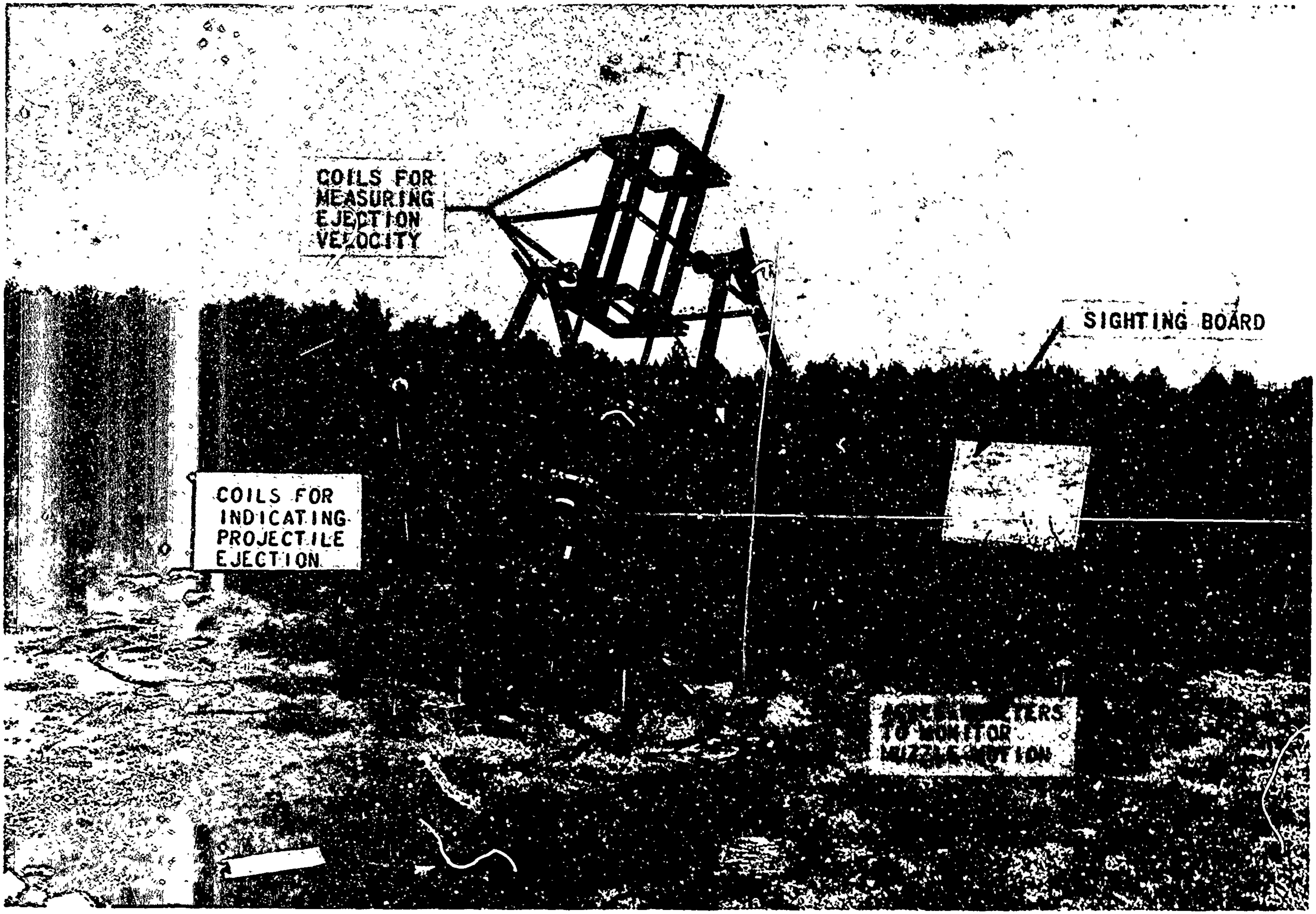


Figure 1. SETUP FOR MORTAR FIRINGS.

support systems were installed in the van as shown in Figure 2 and linked to the event-monitoring instruments at the firing site by appropriate instrument cables.

INSTRUMENTATION DEVELOPMENT AND PROCEDURES

Recording

Owing to the several events to be monitored simultaneously and to the need to correlate these on a common time base, it was desirable that these events should be displayed simultaneously and on a common record. These requirements dictated the use of a high-speed direct-recording oscillograph. The unit chosen for this application was the model 1012 Visicorder manufactured by Minneapolis-Honeywell Instruments. The 1012 Visicorder is a 36-channel direct-recording oscillograph, capable of speeds to 160 ips. Several other features which made this instrument attractive for this application were the incorporation of reference grid lines into the record, flash tube timing increments to 0.001 second, and automatic record length control. In addition, this instrument, which normally uses 12-inch-wide recording paper, was adapted to accept 6-inch-wide paper, thereby affecting a significant savings in costs of recording paper.

All of the events to be monitored, except muzzle velocity, were recorded on the 1012 Visicorder. The muzzle velocity measurement, requiring a better time resolution than could be expected at 160-ips record speed, was recorded separately on a 1.6-megacycle counter chronograph.

The galvanometers which were selected for this application were the Minneapolis-Honeywell type M1650 subminiature galvanometers having a current sensitivity of 9.30 ma/in and a flat frequency response up to 1,000 cps.

Baseplate Reaction

Baseplate reaction was monitored by means of resistance strain gages applied to the neck of the base plug as shown in Figure 3. The gages employed were the C6-121 epoxy-backed, metal-film strain gages manufactured by the Budd

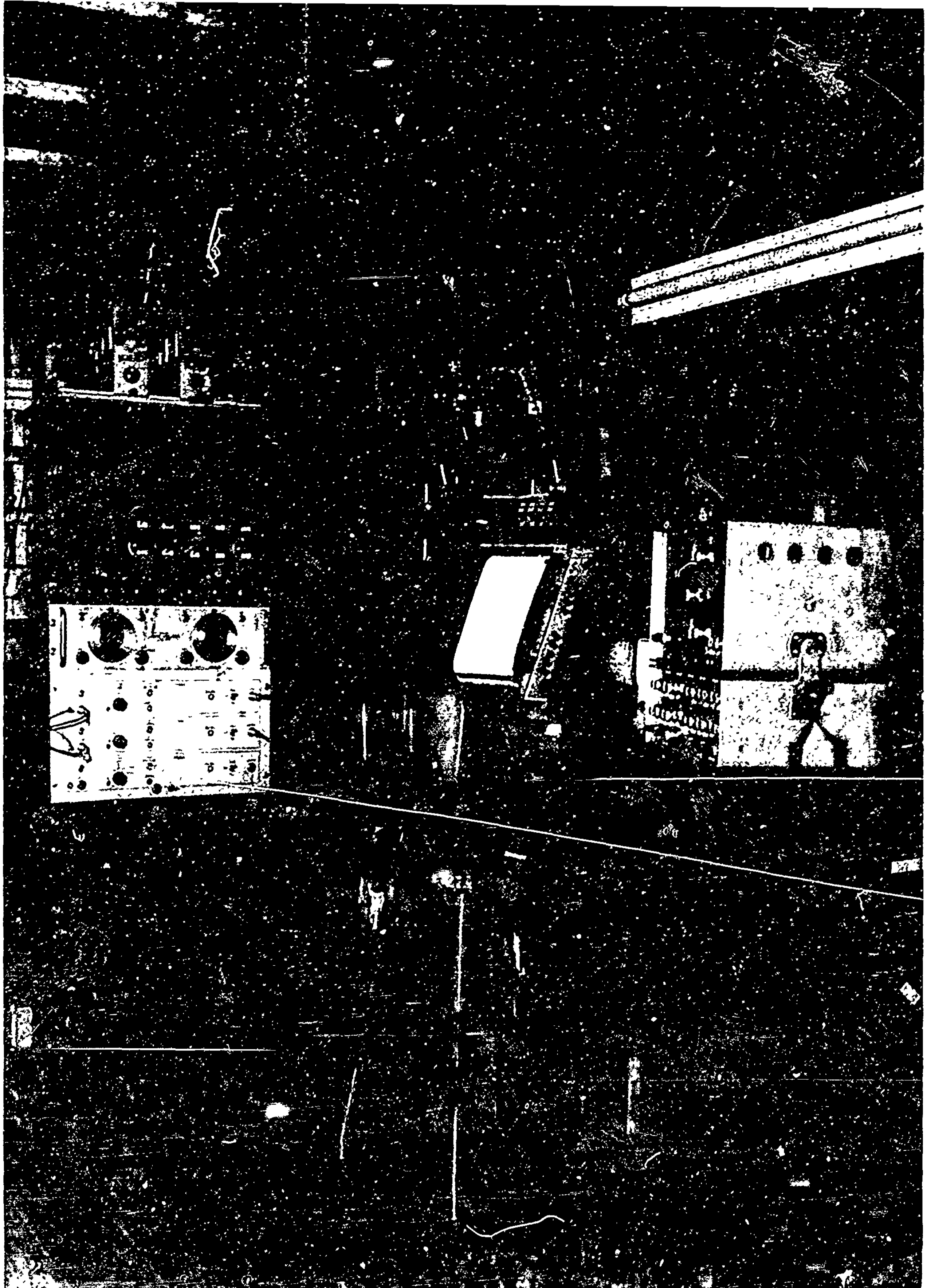


Figure 2. INSTRUMENT AND SUPPORT SYSTEMS INSTALLED IN THE VAN-TYPE TRUCK.

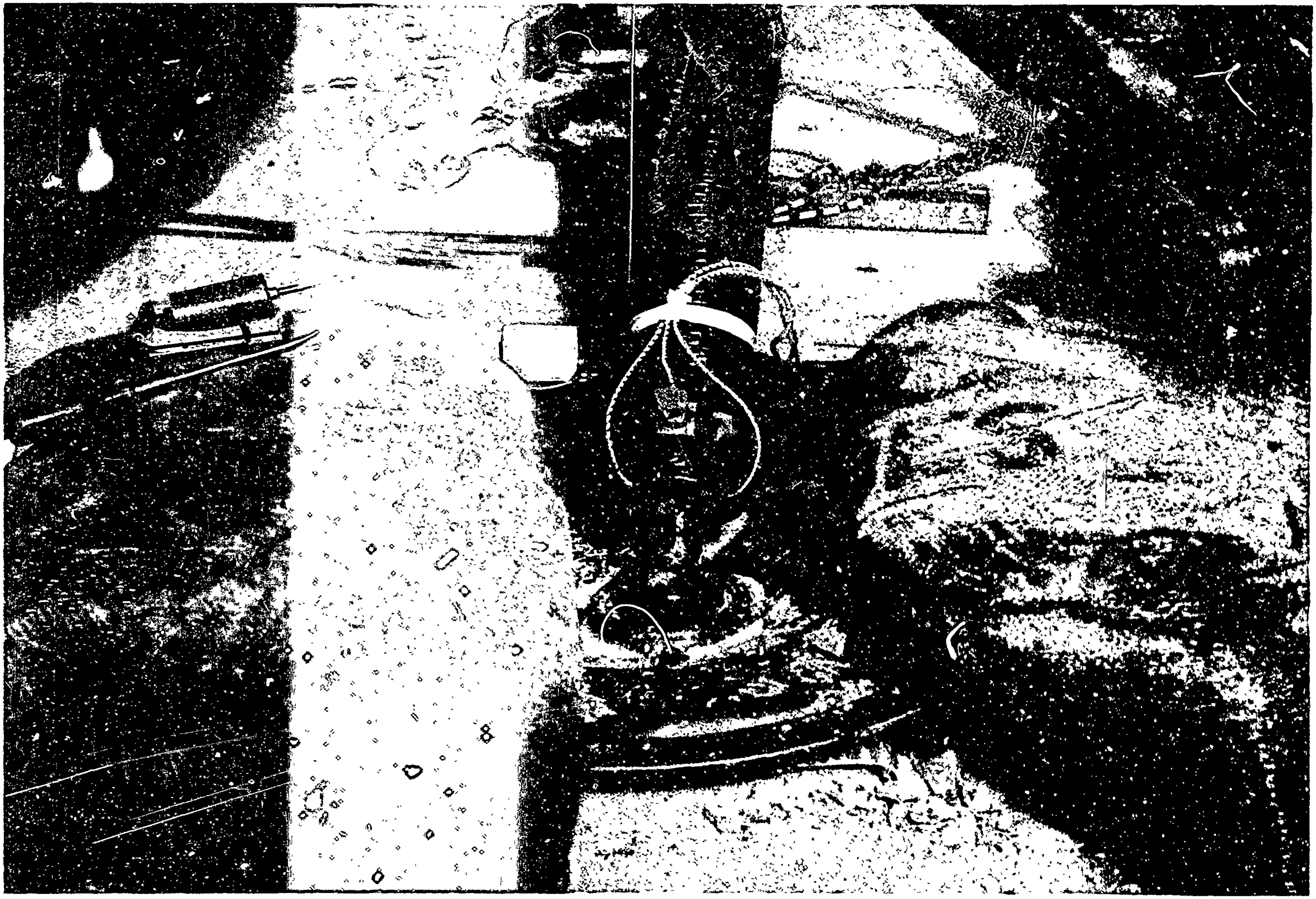


Figure 3 RESISTANCE STRAIN GAGES APPLIED TO THE NECK OF THE BASE PLUG FOR MONITORING BASE PLATE REACTION.

Company, Instrument Division. Because of their small size (0.250 by 0.125 inch) these gages could be applied directly to the neck of the base plugs without the need for modification of the base plugs. This fit was of particular advantage on the T227 base plug which has virtually no neck and a relatively short radius at the juncture of the base plug and body.

Power and amplification for these gage installations was provided by a model 119 carrier oscillator power supply and amplifier system, manufactured by Minneapolis-Honeywell. This carrier amplifier system is a six-channel direct-current information system with a frequency response flat to 1,000 cps. Initially these gages were installed on the base plugs in a two active arm gage arrangement. These gage installations were then coated with Armstrong A-1 cement for waterproofing and protection. These gage installations were calibrated by incremental loading to 80,000 pounds in a Tinius-Olsen compression testing machine at the Naval Weapons Plant, Washington, D. C. During preliminary test firings which were intended to check out the instrumentation systems, these gage installations proved to have good sensitivity and response characteristics, and the magnitude of loads correlated well with previous data which had been reported by other reporting agencies.

During test group 3, however, difficulty was encountered as the first firings were made from concrete; gage installations on both the M29 and T227 barrels failed. This failure was characterized by failure of the protective coating which destroyed the gage installation, and was attributed to brittle failure of the protective coating because of the higher frequency vibrations and accelerations attendant with firing from concrete. The baseplate reaction data obtained from these firings did not correlate with previous data which had been reported by other agencies, but it was assumed that the progressive failure of the protective coating contributed to these inaccuracies and was responsible for the divergences in recorded data.

New gages were installed on the M29 and T227 barrels and Resiweld 600, a resilient epoxy which possessed the required dielectric and mechanical bond properties, was used as a waterproofing and protective coating. No subsequent gage installation failures occurred with the Resiweld protective coatings, but the data obtained from these firings continued to show no correlation with data previously reported by other agencies.

Upon completion of the test group and inspection of the base plugs, the source of this problem area was discovered. Base plugs on both the M29 and T227 barrels been similarly deformed during the firings from concrete. This deformation was characterized by bending of the base plugs at the juncture of the neck and plug body. When viewed from the base end of the barrel, the direction of bend was down and to the right with respect to the firing orientation. The M29 and T227 base plugs respectively were bent 0.111 and 0.132 inch down and 0.191 and 0.034 inch to the right. The combined effects of these permanent bends and additional transient bending which developed under loading provided inconsistent and divergent data which could not be correlated with the original base plug calibrations.

During this time, a portable 100,000-pound hydraulic calibrator had been designed and fabricated to circumvent the need for calibration at the Naval Weapons Plant, and to provide a calibration device which could be used in the field. (Figure 4) Using this calibrator, an attempt was made to recalibrate the deformed base plugs, then to correct and lend credibility to the recorded baseplate reaction data. This recalibration attempt was wholly unsuccessful because of the combined effects of the permanent deformation of the base plugs and the additional spurious bending which occurred under loading and prevented the establishment of a reproducible calibration. The data which had been recorded with these deformed base plugs was set aside as invalid.

In future attempts to monitor this event, four active arms, or other suitable bend compensating gage arrangements, should be used to cancel out transient and localized bending. It should be noted, however, that, while compensating gage arrangements can cancel out transient and localized bends, they cannot be expected to negate the effects of gross bending as encountered in these firings. Care should, therefore, be exercised to preclude test conditions which exceed the bend compensating capacity of the gage installations.

Figure 4. PORTABLE 100,000-POUND HYDRAULIC CALIBRATOR.

Chamber Pressure

Chamber pressure was monitored by means of a small strain gage type ferrule pressure transducer designed and fabricated by Atlantic Research for this application. (Figure 5) Using this transducer and its "floating" mount ring, it was possible to gain direct transducer access to the chamber with an absolute minimum of modification to the mortar barrel.

The sensing elements used in these transducers were the C6-121 epoxy-backed metal-film strain gages. Power and amplification for these gages installations were provided by the carrier amplifier system.

These transducers were calibrated by incremental loading to 10,000 psi on an Ashcroft dead-weight calibration system. This calibration was checked in the field daily on a hydraulic system which also provided power for the 100,000-pound baseplate reaction calibrator. Pressure in this system was indicated by Ashcroft duragages having rated accuracies of 0.5 per cent. These gages were periodically checked against the dead-weight system to insure agreement.

The original transducer ferrules which had been fabricated from 1010 steel proved unsatisfactory, and new ferrules were fabricated from 4130 steel and heat treated. These new transducers possessed good sensitivity and linearity characteristics during calibration and checkout. During firing, however, the gage output was modulated by an external source. This modulation of the firing record precluded reduction of these records to accurate pressure data.

From initial tests it was concluded that the temperature compensating gage element, due to its location or orientation on the ferrule, was responding to mechanical loads induced into the ferrule by the high level of vibration and acceleration environment which is present at the base of the barrel. A transducer which contained no temperature compensating element was immediately fabricated and tested. The results of these tests clearly demonstrated the source of gage output modulation. These tests also demonstrated that, due to the location and construction of the transducer and to the very short event time involved, a temperature compensating element was not required for satisfactory performance of the transducer.

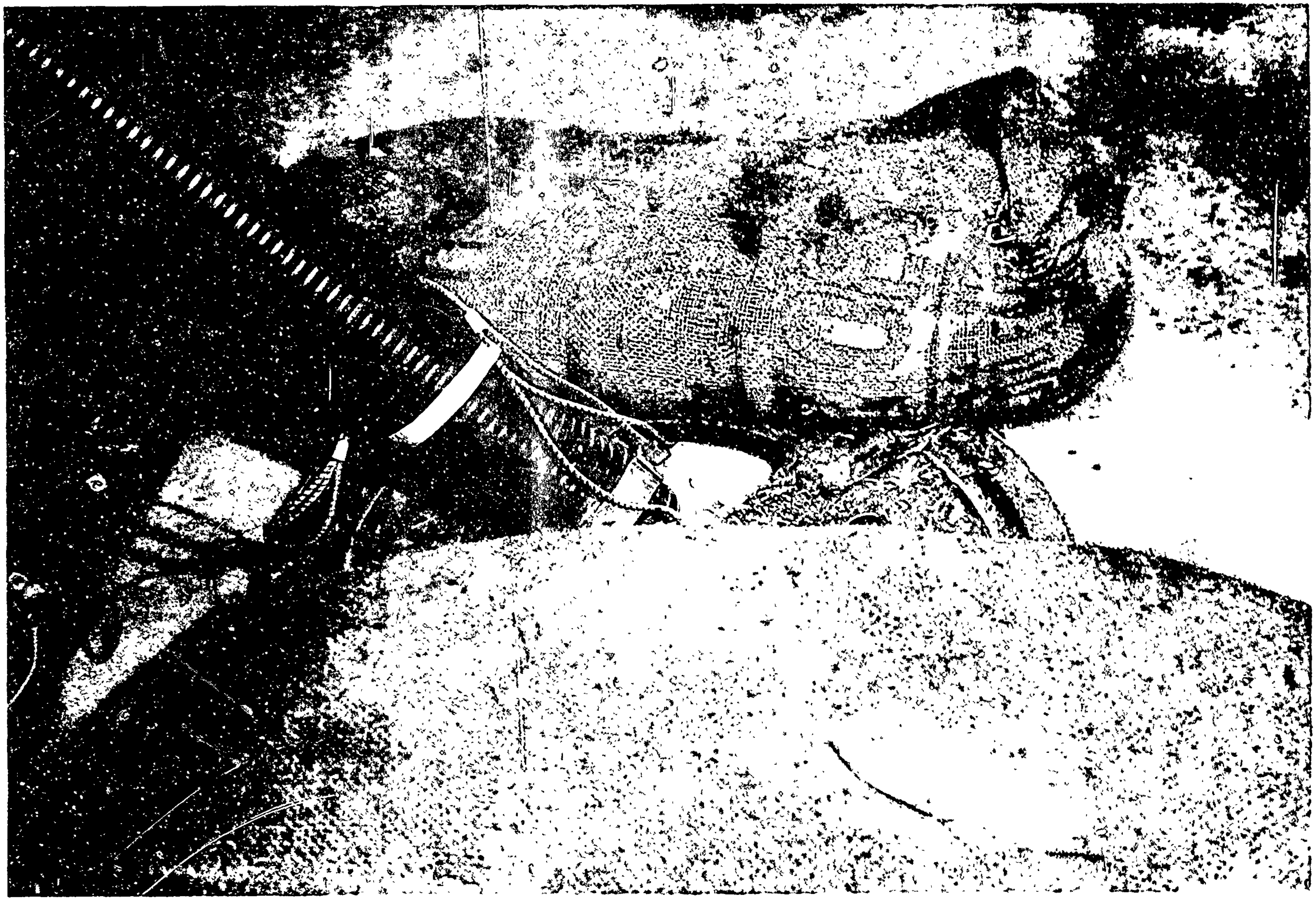


Figure 5. INSTRUMENTATION FOR MONITORING CHAMBER PRESSURE.

Monitoring of pressure by these strain gage type ferrule transducers proved satisfactory, and no further changes were necessary in the chamber pressure measuring system.

Sight Acceleration

Sight acceleration was monitored by means of ±1,000g unbonded wire accelerometers mounted on a sight simulator. The frequency response of these unbonded wire accelerometers permitted investigation only of those accelerations having frequencies of considerably less than 1,000 cps. These accelerometers monitored transverse and longitudinal accelerations which appeared at the center of gravity of the sight unit, under the various firing conditions specified for test group three. (Figure 6) The sight simulator duplicated the weight and vertical center of gravity of the Sight M34A2 and could be rotated around its own mounting axis to maintain the correct relationship between the center of gravity of the sight and the mount yoke at elevations of 45 and 70 degrees.

This system for monitoring sight accelerations proved satisfactory, and no changes were necessary in the system.

Bipod Leg Loads

Bipod leg loads were monitored by means of strain gages applied directly to the bipod legs. (Figure 7) The strain gages selected for this application were the SR-4 type A-14, manufactured by Baldwin Lima Hamilton. As in the case of the other strain gage systems, power and amplification for gage installations were provided by the carrier amplifier system.

Of the several load components and vectors which occur on a given leg, the axial load as delivered down the leg to the bipod foot is most truly representative of the total loads in that leg. Proper location and orientation of the gages were essential, since the gages should reflect the full axial component of load, yet remain unaffected by transient or localized bending. A spot approximately 2 inches above the bipod foot was selected as the optimum location and

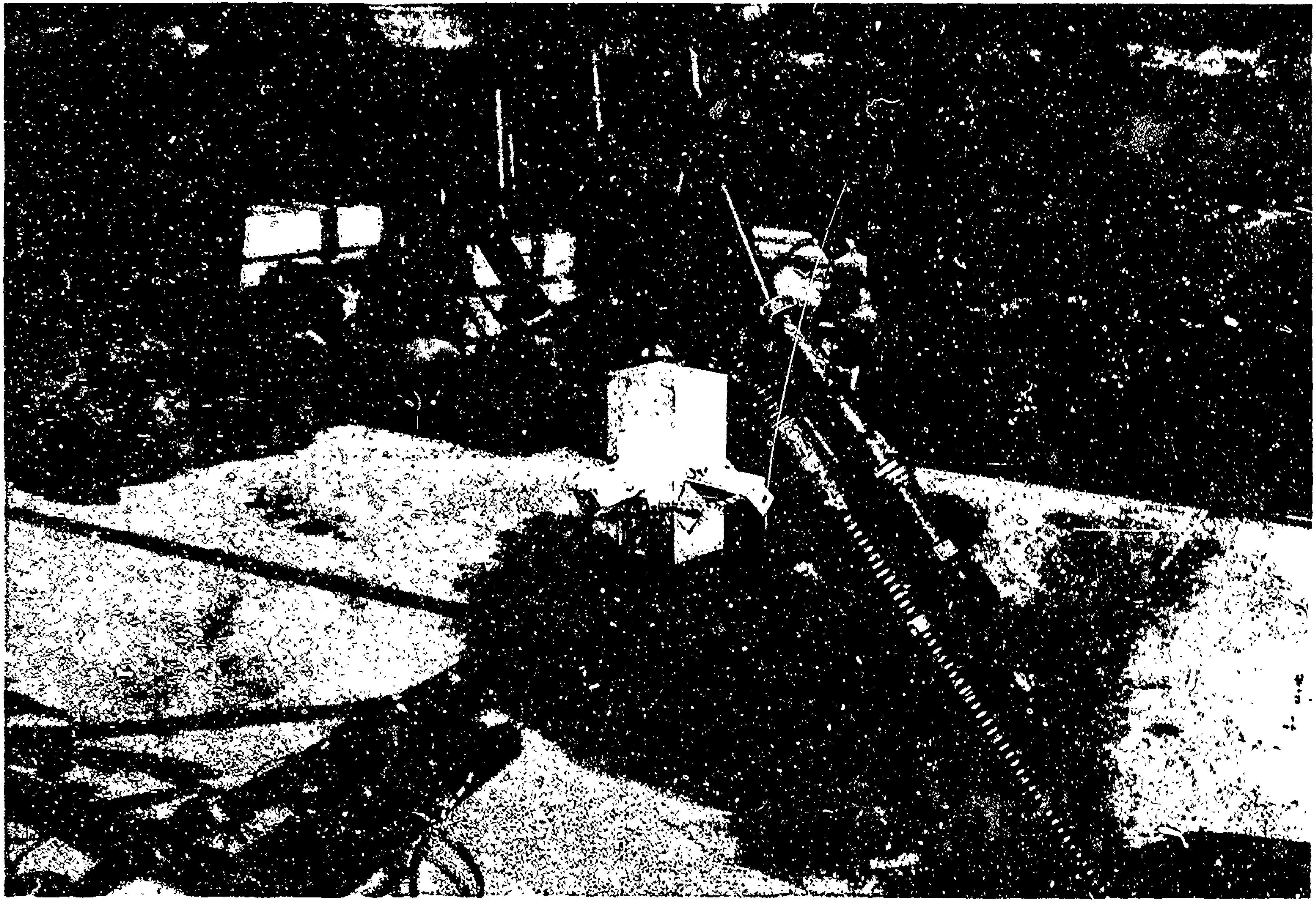


Figure 6. ACCELEROMETERS MOUNTED TO MONITOR SIGHT ACCELERATION.

Figure 7. INSTRUMENTATION FOR MONITORING LOADS ON BIPOD LEGS.

two active arm gage installations were made on a pair of M23A1 bipod legs. During calibration and preliminary tests these gage installations proved difficult to calibrate up to 200 pounds. Small asymmetries in loading produced significant bending due to the length of the legs, and, owing to the heavy construction of the left leg of the M23A1 mount, the two active arm gage installations did not provide adequate load sensitivity.

Four active arm gage installations were then made on each leg of a M23A1 mount. Calibration was accomplished without difficulty and the four active arm gage installations provided adequate load sensitivity for the left leg.

Gage installations were made on all legs and calibration accomplished without incident. In addition to the calibration, asymmetric loading tests were performed to demonstrate insensitivity of these installations to bending and asymmetric loads, and thus develop a high level of confidence. The system proved satisfactory and no additional changes were necessary.

Ejection

Time of ejection of the projectile was defined as that time at which the tail fins cleared the muzzle. This time was established by positioning a passive magnetic induction coil so that the magnetic center of the projectile passed through the coil center as the tail fins cleared the muzzle. (Figure 1.)

The projectile was magnetized in a direct current coil prior to firing, inducing a voltage into the ejection coil windings as it passed through the coil. Output from the ejection coil was amplified and recorded on the oscillograph. The event was characterized by a 180 degree shift in polarity of the coil output. This system proved satisfactory and no changes were necessary.

Muzzle Velocity

During preliminary tests the initially installed photoelectric screen system responded microphonically to blast, giving spurious readings. Efforts to isolate the microphonic components were only partially successful and the system was abandoned.

Two passive magnetic induction coils similar to the ejection coil were fabricated and mounted in the velocity coil framework. (Figure 1) These coils detected transit of the projectile between two points some three feet apart. Output from the coils was amplified, shaped and recorded on a 1.6 megacycle counter chronograph manufactured by Potter Instruments.

Initial testing with this system resulted in consistent recording of velocities some 8 per cent in excess of the accepted velocities for a given projectile and charge. Careful recalibration and study of the measurement system failed to reveal the source of the velocity error.

A random sample of the ammunition provided for this contract was taken, and the weight of these projectiles checked against the normal in-flight weight. The M362 projectiles stripped of propellant and ignition charge were found to weigh 8.18 pounds as opposed to the specified weight of 9.34 pounds. Both the M362 and M43A1 projectiles had been inert loaded to a total weight which was less than the normal in-flight weight.

Rather than to return the ammunition, the task of bringing the projectiles up to the correct in-flight weight was assigned to Atlantic Research. For the M362 projectile, this was accomplished by machining cylindrical steel slugs of the correct weight, which fitted into the booster cavity and were locked into place by the closure plug. Since the M43A1 projectiles had been supplied without closure plugs, the slugs were threaded and screwed directly into the fuze well.

Correct velocities were recorded with the modified projectiles, and no changes were necessary in the measurement system.

Muzzle Motion (Acceleration)

It was determined during preliminary study of the over-all program approaches that the most singly significant measurements to be made were measurements which would reveal the pattern of motion of the muzzle while the round was in residence in the bore, and provide a means for relating these motions to the other systematic events. It was felt that all systematic asymmetries and significant components of motion would be reflected at this point, and that the over-all influence of these factors on weapon accuracy and stability might best be determined by these measurements.

A careful study was made of the approaches and techniques which might be employed to make these measurements. Of particular concern were the numerous and often conflicting requirements for accuracy, resolution, light weight, ruggedness, ease of setup and calibration, ease of data reduction, adaptability to a field environment, and finally compatibility of the system with a firing rate of approximately 6 rounds per hour. This study revealed that the only approach that held any promise of satisfying these requirements was use of accelerometers.

First, unbonded wire strain-gage-type accelerometers were used. At that time, the sole source of unbonded wire accelerometers was the Statham Instrument Company. These accelerometers functioned on a strain gage principle and could therefore be easily and quickly integrated into the over-all instrumentation setup. The frequency response of these accelerometers was relatively low, extending only to 750 cps, but it was assumed that significant motions of the muzzle would fall within this frequency bandwidth.

Power and amplification for the accelerometers were provided by the Minneapolis-Honeywell carrier amplifier system and the acceleration traces were recorded on the direct-recording oscillograph along with the other events being monitored.

Two accelerometers were mounted on a mounting ring at the muzzle. They were located 90 degrees from each other so that they monitored accelerations which occurred in two planes perpendicular to the bore axis. With respect to the barrel the accelerometers monitored accelerations in the elevation and azimuth planes. (Figure 1)

In quick succession, 25g, 50g, and 350g accelerometers failed. Next, 1,000g accelerometers which had a maximum rated range of ±2,000g were tried. The first of these failed after 74 firings; failure was attributed to one of two conditions: (1) either the accelerometers were failing because of a high-frequency component of the acceleration spectrum which was of sufficient magnitude to cause failure but which the accelerometers were unable to detect, due to its low frequency response; or (2) that the accelerometers were failing due to cross axis loading caused by the high-level accelerations associated with recoil of the barrel.

These 1,000g accelerometers represented the highest range unbonded wire accelerometers which could be obtained as a standard item. Statham Instruments indicated that accelerometers in the 5,000g range could be made available within three months. A program delay of three months was not acceptable, and the decision was made to pursue an alternate approach.

The second approach was through the use of piezo accelerometers. Due to the severe program slippages already incurred, and the need for resolving whether accelerometers could indeed be successfully employed to monitor muzzle motions, two types of piezo accelerometer systems were obtained and tests initiated.

The first system was manufactured by the Kistler Instrument Company and was made up of two natural quartz accelerometers and a dual channel, battery-powered charge amplifier and integral calibration system. The accelerometers had a charge sensitivity of 5 pk-cb/pk-g, a maximum rated cross axis, sensitivity of 2 per cent, and weighed 40 grams each.

The second system was manufactured by Columbia Research Laboratories and consisted of two ceramic crystal accelerometers and a three-channel piezo voltage amplifier system. The accelerometers had a voltage sensitivity of 20 pk-mv/pk-g, a maximum rated cross axis sensitivity of 5 per cent, and weighed 15 grams each.

These two piezo systems were received, checked out, and immediately sent into the field for evaluation with respect to each other and with respect to the unbonded wire accelerometers.

During initial testing the three systems were generally in good agreement on amplitudes of accelerations in the range of 0-1,000 cps. Divergences occurred between the piezo systems and the unbonded wire system at frequencies above 1,000 cps, due to the limited frequency response of the unbonded wire system.

During these firings the piezo systems both gave indications of large accelerations just after ignition of the propellant charge, while the unbonded wire accelerometers gave no such indications. (Figure 8) This raised suspicion that the piezo accelerometers were responding to cross axis loads resulting from recoil of the barrel. Correlation of previously recorded recoil acceleration profiles indicated that times of onset of recoil accelerations and of these spurious piezo signals did coincide. (Figure 9)

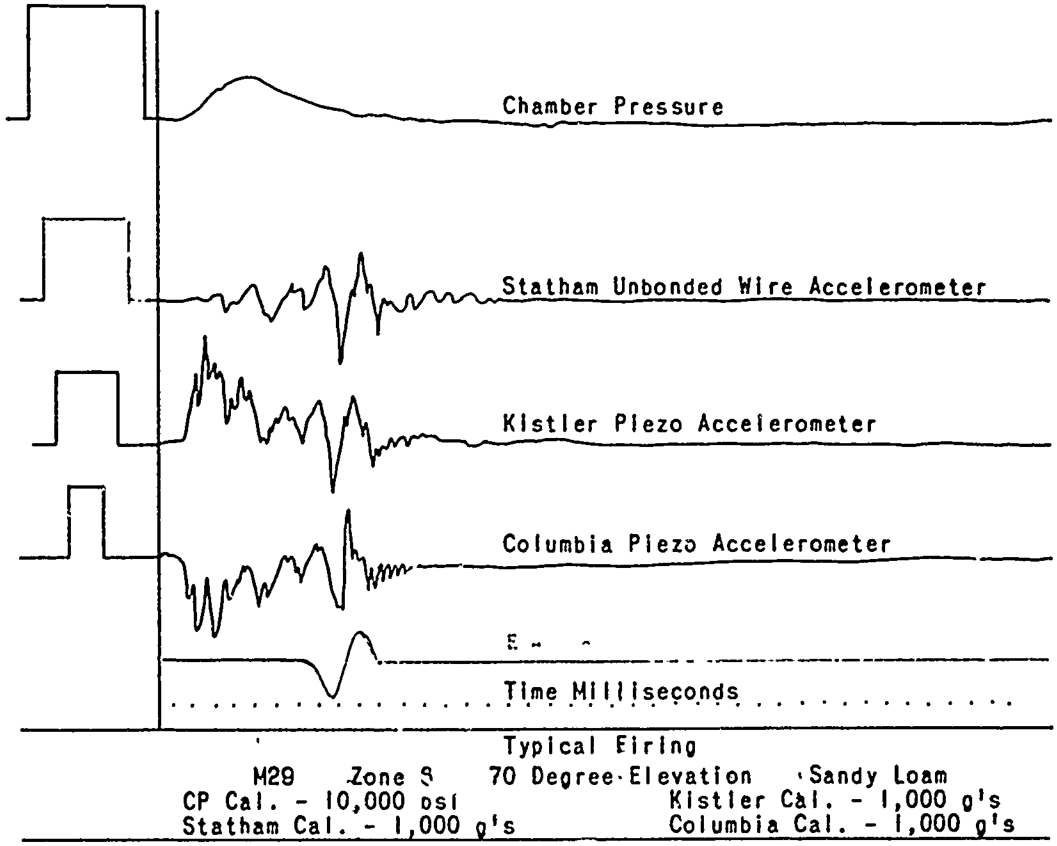
Because of the correlation between onset of recoil accelerations and of the spurious piezo signals, and, further, because of the lack of correlation between the piezo and unbonded wire accelerometers, it was concluded that the piezo accelerometers were responding to cross axis loads due to recoil of the barrel. In addition, both piezo systems evidenced pronounced shifting of record trace baselines during these firings. (Figure 8) The combination of these completely precluded reduction of the piezo accelerometer records to meaningful muzzle displacement data.

Both types of piezo accelerometers suffered structural failures during these firing tests and had to be returned to the vendors for rebuilding and modifications which would provide the structural integrity required for them to survive the severe muzzle environment.

It was evident that only a laboratory investigation, under rather optimized and controlled conditions, might permit isolation of the causes and effects and expedite determinations as to whether the piezo accelerometer systems were indeed adaptable to this task of determining muzzle motions by accelerometry.

LABORATORY TESTS—PIEZO ACCELEROMETERS

The principal tool in the laboratory investigation was the vertical drop hammer shown in Figure 10 on which the accelerometers were mounted for impact loading at relatively high g levels. The hammer system consisted of the hammer



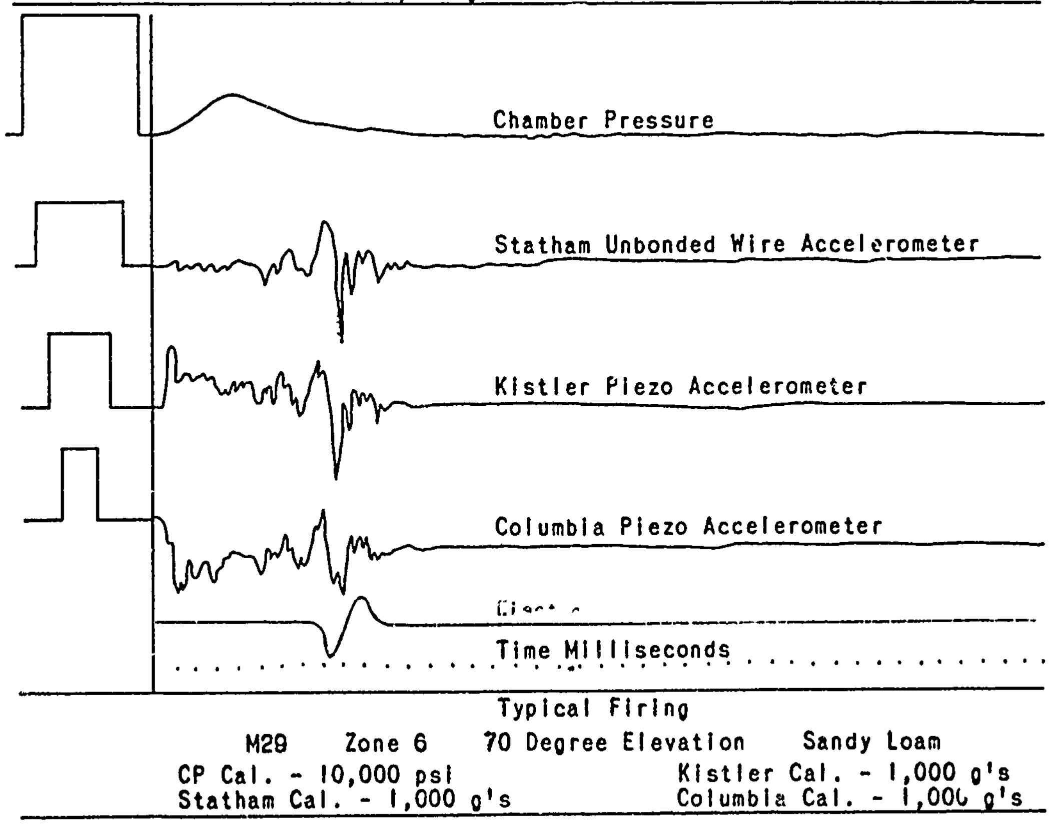


Figure 8. Comparison of Piezometric and Wire Accelerometer.

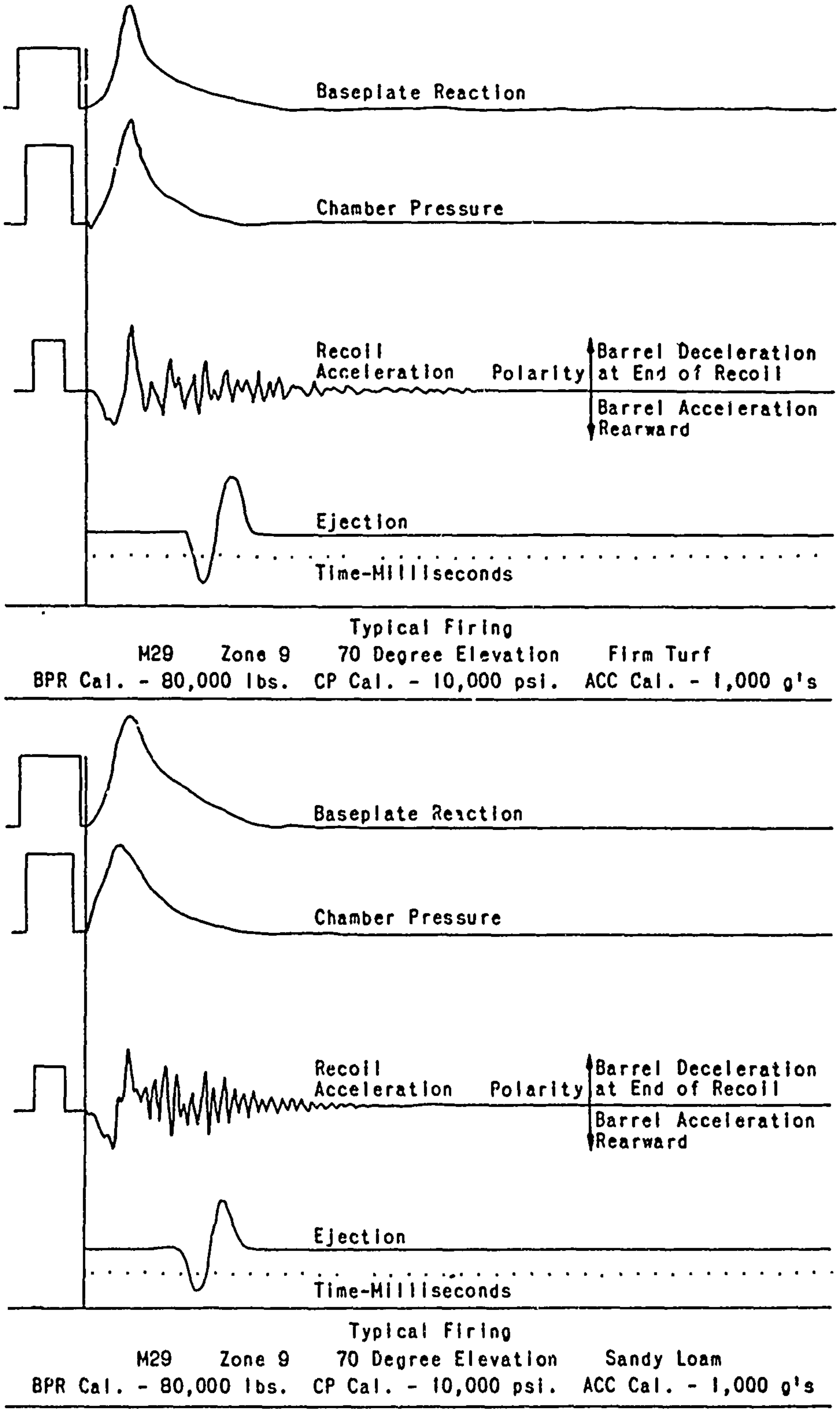


Figure 9. Recoil Acceleration Records.

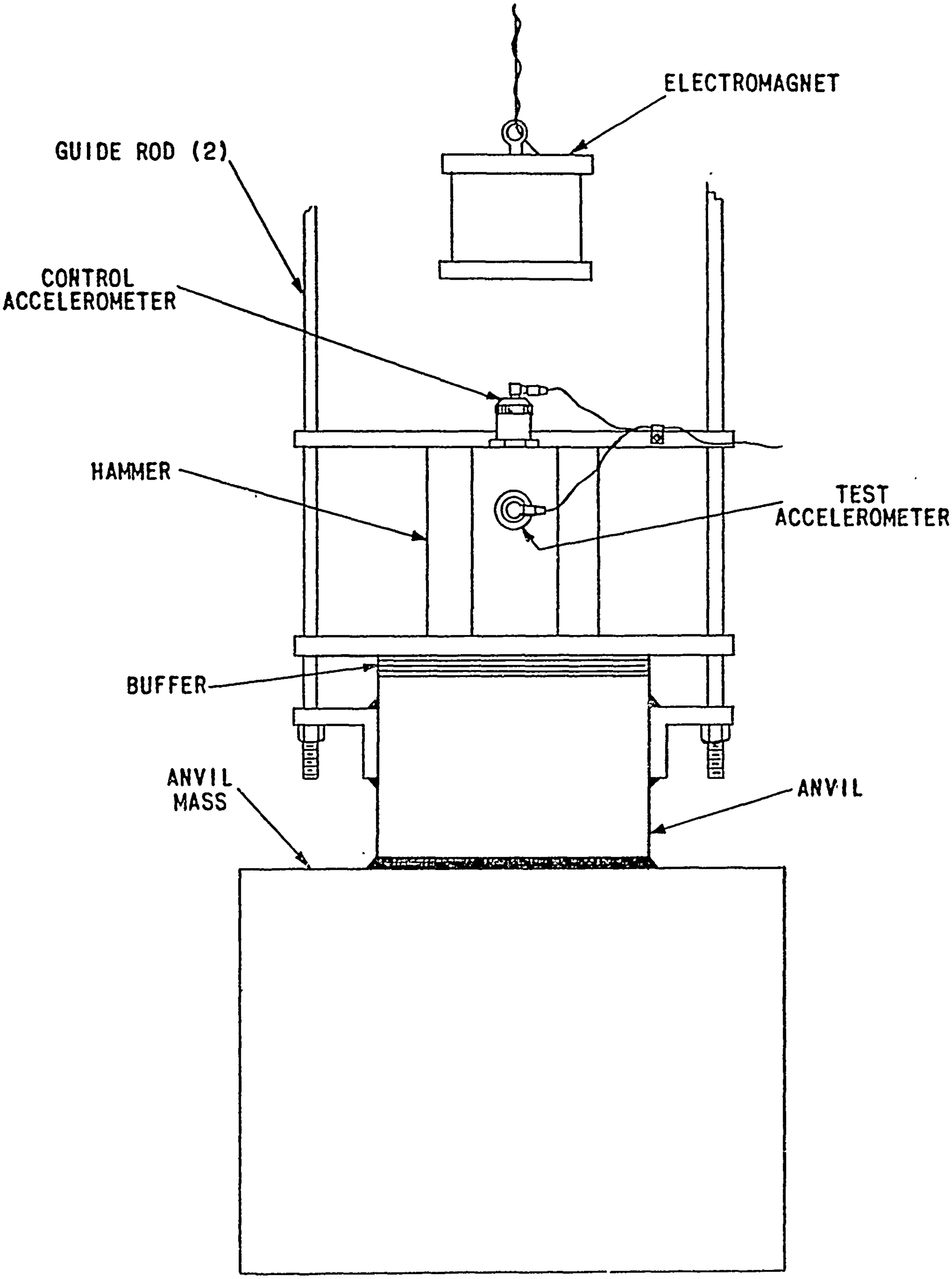


Figure 10. Vertical Drop Hammer.

itself which was machined from 3-inch hexagonal steel stock; 0.5-inch diameter guide rods which served to keep the hammer in vertical alignment during fall and impact; an anvil 12 inches in diameter and weighing 375 pounds; rubber buffers of various thicknesses and constructed to control g level and dwell time of the shock load. Guide rod alignment and cross member and guide rod clearances were minimized to insure good vertical alignment of the hammer during fall and to minimize horizontal components of hammer motion on impact. Initial testing of the hammer insured that surface ripple due to impact and bulk modulus effect was negligible. Outputs from the respective accelerometer amplifiers were recorded on the Minneapolis-Honeywell 1012 Visicorder at record speeds of 160 ips.

In addition to the two original piezo accelerometer systems, additional piezo accelerometers as well as those manufactured by other companies were obtained for evaluation. These included units from Endevco, Columbia, Kistler, Gulton, and United Aerotronics.

Two accelerometers were mounted on the hammer for each test. The first was a control accelerometer and the second was the accelerometer being evaluated. Both accelerometers were mounted on top of the hammer and one or more drop tests run to establish level of agreement between the two. The test accelerometer was then mounted on the side of the hammer so that it was subjected to cross axis loading. The control accelerometer remained in its original position to confirm the level of cross axis load being applied to the test accelerometer.

Results of the laboratory evaluations of the piezo accelerometers on the vertical drop hammer may be summarized as follows. In tests at the 300-600g level, the lowest cross axis response of any accelerometer tested was in excess of 9 per cent, with response of some units as high as 43 per cent. In the tests at the 1,000g level, the lowest cross axis response of any accelerometer tested was in excess of 12 per cent, with response of some units as high as 54 per cent. It was concluded that most of the accelerometer response to high-level cross axis loading was the result of cantilevering and other mechanical loads induced into the accelerometer case by high level transverse accelerations. These mechanical loads were transmitted to the crystal stack, translated into electrical response, and appeared as spurious acceleration profiles on the acceleration record.

The drop hammer was capable of generating a single acceleration pulse of approximately 1,000g with a dwell time of 0.25 millisecond and in one plane perpendicular to the accelerometer's sensitive axis. The mortar imposed two simultaneous cross axis loads which were oscillatory in nature. One was in excess of 1,000g with dwell times up to 2 milliseconds. The second approached 1,000g and had frequencies up to 1,500 cps.

The cross axis acceleration environment on the mortar was much more severe than could be produced on the drop hammer; therefore, it was concluded that the spurious response of the accelerometers to this environment was significantly greater than was evidenced on the drop hammer.

In addition, baseline shifts occurred on the drop hammer as they had during the firing tests. This shifting of baselines was related to numerous factors which may all be lumped under "coupling and mounting." This includes mounting surface hardness and preparation, mounting methods, fixtures techniques, etc. It was concluded that these baseline shifts which occur resulted from the influence and interaction of these elements under dynamic and particularly transverse loading. Because of the restricted scope of these laboratory tests, a full and detailed understanding of this phenomena was not afforded. Since they continued to occur even with the ground mounting surfaces afforded on the drop hammer, serious doubt existed as to whether mounting could be made on the mortar which would prevent these shifts.

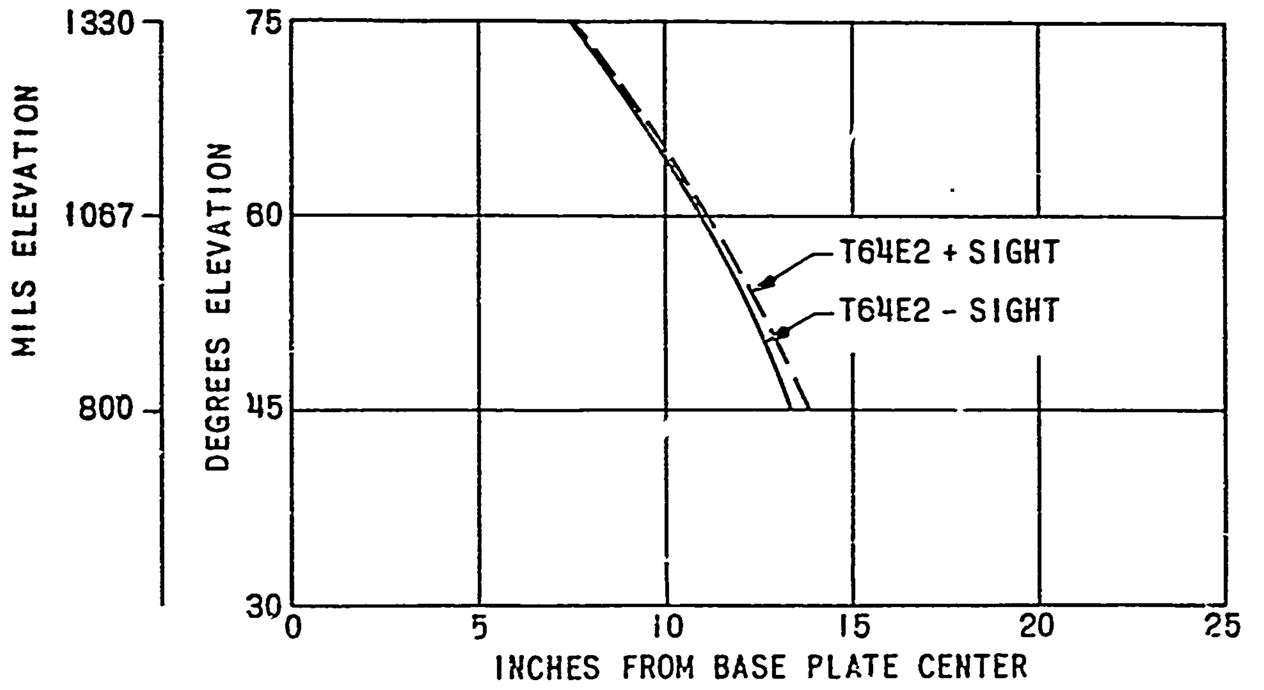
Owing to the discrepant performance of the piezo accelerometers, and in view of the continued high incidence of baseline shifting, which precluded reduction of the piezo accelerometer records to meaningful displacement or position information, it was concluded that the piezo accelerometer systems and usage techniques are not satisfactory for this application.

LABORATORY STUDIES—CENTER OF GRAVITY

A laboratory study was made to determine the location of the center of gravity of the M29 and T227 mortars over the normal ranges of weapon elevation and traverse. Data were taken with the Sight M34 in place, then removed, to determine the influence of the sight unit, when mounted in its current location, on this parameter.

In addition, a study was made of the differential static loads which occur in the bipod legs of the M23 and T227 mounts, over the normal ranges of traverse. As in the center of gravity study, data were taken with the Sight M34 in place, then removed, to determine its influence on this parameter.

The data obtained from these studies are graphically illustrated in Figures 11, 12, and 13.



DISTANCE, BIPOD FOOT CENTER TO BASE PLATE CENTER			
MOUNT	ELEVATION		
	1330	1067	800
T64E2	39.830	42.937	42.937
M23A1	40.531	47.406	47.156

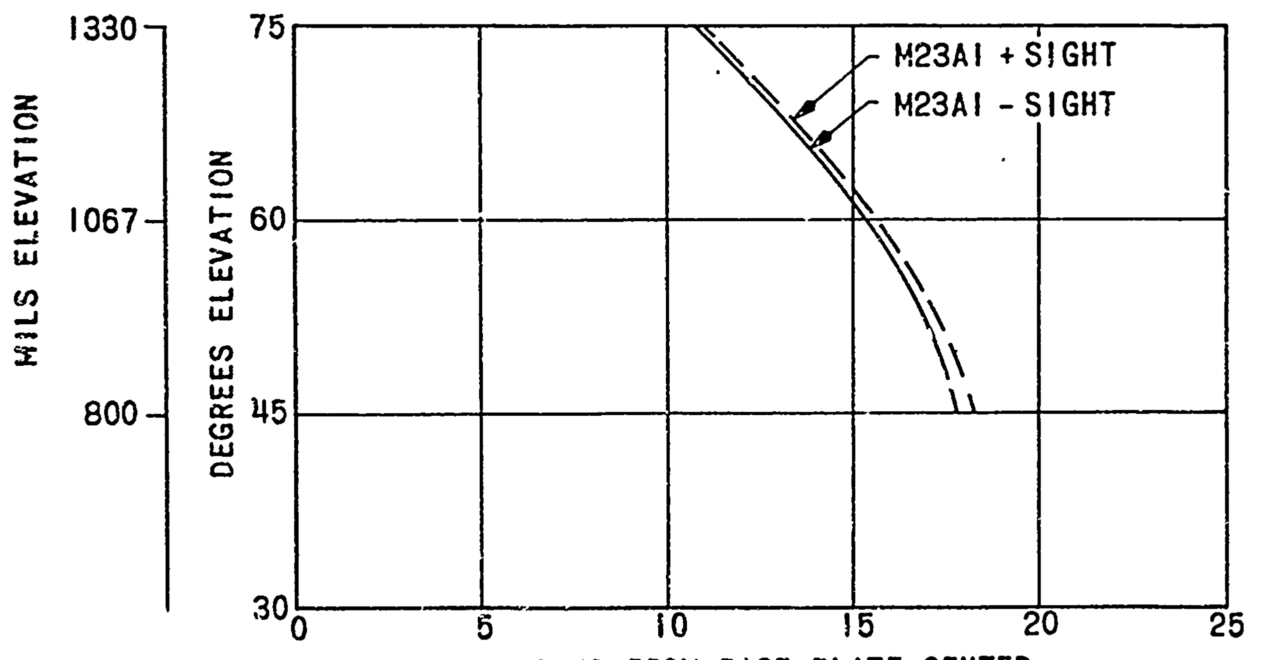


Figure 11. Center of Gravity Location versus Elevation.

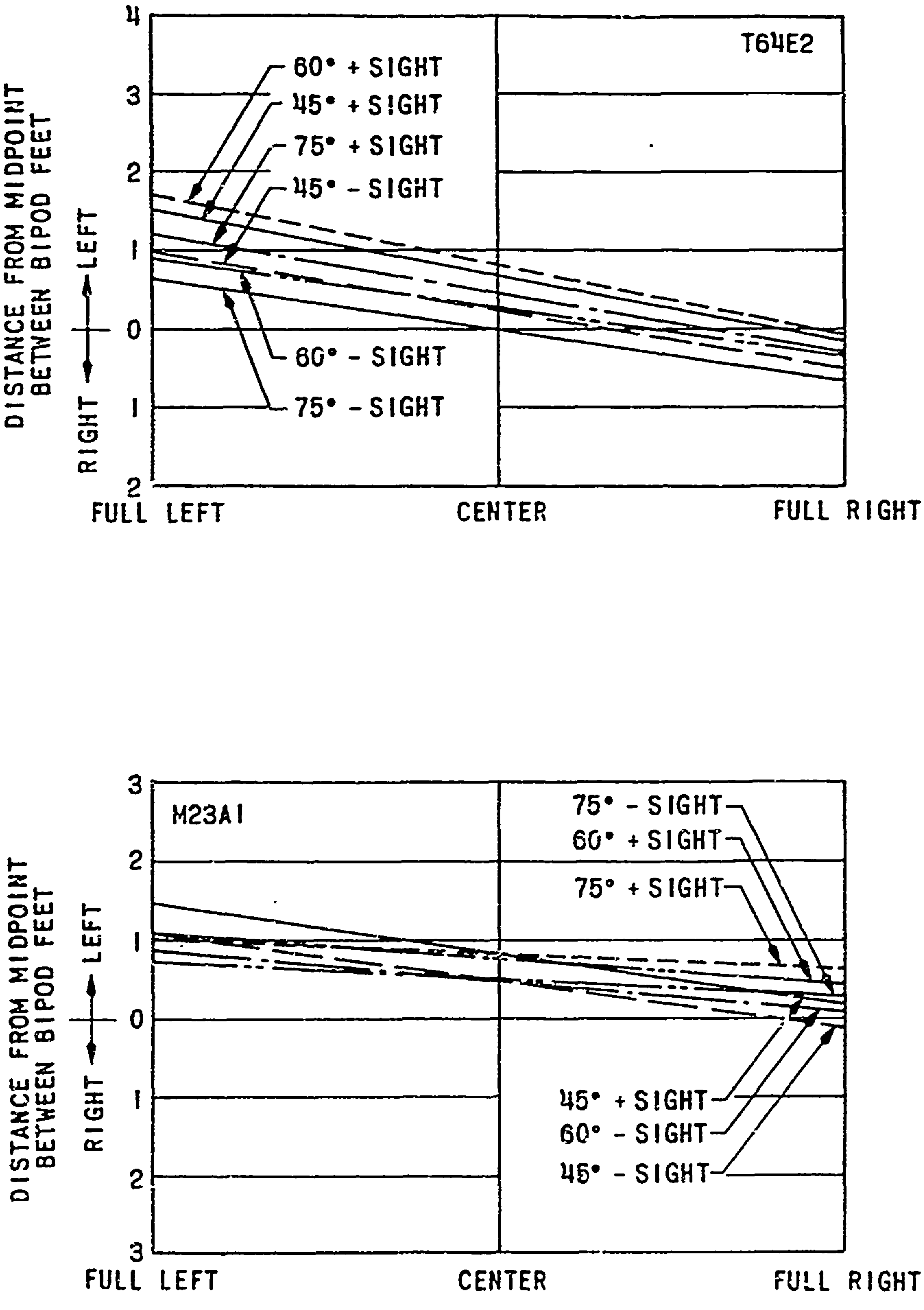
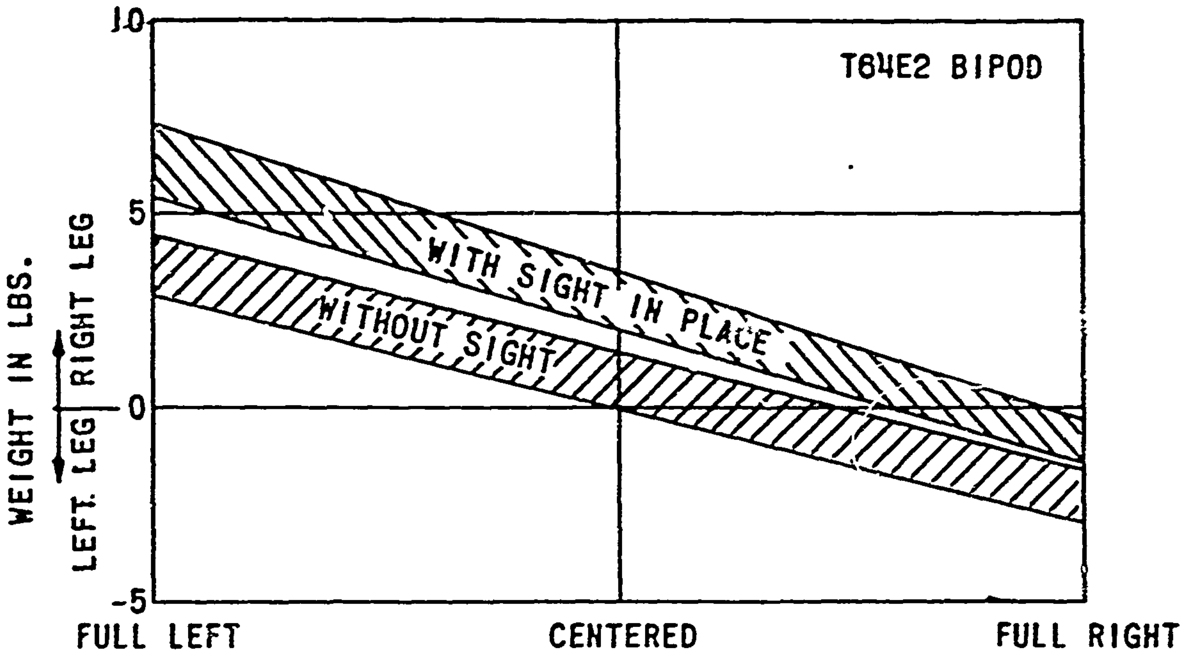


Figure 12. Center of Gravity Location versus Traverse.



TRAVERSE

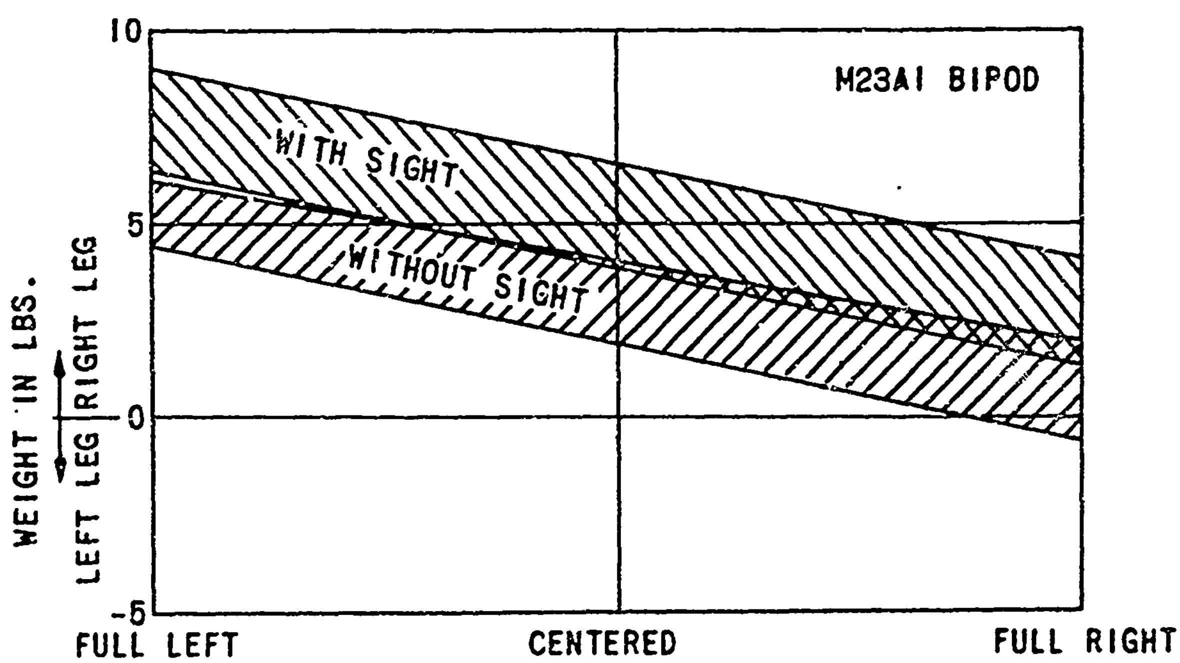


Figure 13. Differential Load on Bipod Legs 81MM Mortar.

TEST FIRINGS

In the following section, the data obtained from the firing program will be given, and insofar as possible, analyzed to determine whether effects have been demonstrated which may influence future mortar designs.

The proposed firing program was established by a Firing Program Directive, prepared by Atlantic Research Corporation and approved by the contracting agency. This document is incorporated into this report as an Appendix.

The firing program as proposed was not completed during the term of this contract. Failure to complete the entire program was due to an unfortunate sequence of factors, which, it is suggested, were beyond the control of the contractor or the contracting agency. Although many of these factors have been discussed previously in this report, it is worthwhile to summarize them at this point.

a. The error in inert loading the test rounds which were furnished to the contractor resulted in approximately 150 rounds of underweight projectile being fired before the error was caught.

b. The restrictions placed upon use of the firing range by the authorities at Camp A. P. Hill, over most of the term of the contract, either prohibited firing or restricted firing to the hours of darkness.

c. Structural failures of several components of the mortars were caused by the severe firing conditions.

d. Failure of the initially planned technique for determining muzzle motion to provide reliable and useful information necessitated an extensive instrumentation study which penalized the program in funds and time.

Despite these factors much useful data was obtained, and in working with the instrumentation problems, many techniques were developed which will be exceedingly useful in future studies of mortar mechanics.

The firing data presented herein were reduced from individual test firing traces to permit tabulation of and correlation by numerical values. The individual test firing traces will be bound, cross referenced to the numerical data, and forwarded to Watervliet Arsenal under separate cover.

Test Group 1

The objective of this test group was given in the Firing Program Directive:

"The objective of this test group is to investigate the performance parameters of the basic mortar systems M29 and T227E2, employing the Round, H. E., M362, over a spectrum of 108 variables and to collect a basic body of performance data to which subsequent tests, which embody additional variables, may be correlated."

In addition, a primary purpose of this group of tests was to determine whether dynamic behavior of the mortars occurring before shot ejection could contribute to firing inaccuracies. This required the use of a wide range of emplacement conditions, elevations, and propellant charge increments. The use of the two mortars, the M29 and the T227E2, was further required to determine if the large decrease in mass of the latter adversely affects the dynamics of the system.

The firing of Test Group 1 was terminated after firing 207 rounds due to the continued failure of the highest range unbonded wire accelerometers which were immediately available; the discrepant and unsatisfactory performance of piezo accelerometers in this application, and in view of the failure of alternate approaches to satisfy the requirement for monitoring patterns of motion of the muzzle.

The data recorded from those 207 firings, the data correlation, and conclusions which may be made are as follows.

1. Mortar Dynamics Analysis

In the early phase of the program, a thorough study was made of possible techniques for determining important dynamic behavior. The method selected was the employment of two accelerometers, mounted to the muzzle and oriented so that one would respond to motion in the elevation plane and the other to motion in the azimuth or traverse plane. The use of various still and motion photography techniques, mechanical indicators, and even radiographic methods was considered but rejected.

Typical firing records which show the output of the two accelerometers are shown in Figure 14. It was initially believed that for maximum usefulness the accelerometer data should be integrated with respect to time from time zero to shot ejection (clearance of the tail fins). This integral, it was felt, would provide information as to any significant motion of the barrel at ejection which would cause the round to deviate in its flight. This data, however, proved to be unusable as the characteristic record of a muzzle accelerometer showed an oscillatory acceleration increasing from time zero until a maximum was reached, usually just prior to shot ejection, and then decreasing rapidly. The integrals of these records showed no consistency, and have been discarded. For the purpose of this analysis, the peak acceleration in both directions in each of the two planes has been recorded. The magnitude of this peak (vibratory) acceleration is then compared for the various firing conditions.

The averages (usually for six rounds) of baseplate reaction, chamber pressure, positive and negative acceleration peaks in each of the two planes, ejection time, and muzzle velocity for the rounds of Test Group I are tabulated in Table I.

This table has been prepared in such a manner that the effect of each variable firing condition upon the recorded parameters can be quickly determined.

From an analysis of the acceleration measurements several interesting conclusions are apparent:

a. Over the entire spectrum of firing conditions, the maximum accelerations recorded for the T227E2 mortar are significantly greater than those observed for the M29 mortar.

b. The maximum recorded accelerations for both mortars showed a marked increase when the change was made from firm turf to a sandy loam emplacement.

A study was also made of the average time intervals from time zero to the occurrence of the peak accelerations. Although some variance was encountered, when these times were averaged for all firings at each of the three zones, 6, 8, and 9, it was found that the maximum occurs just as the nose of the round emerges from the muzzle.

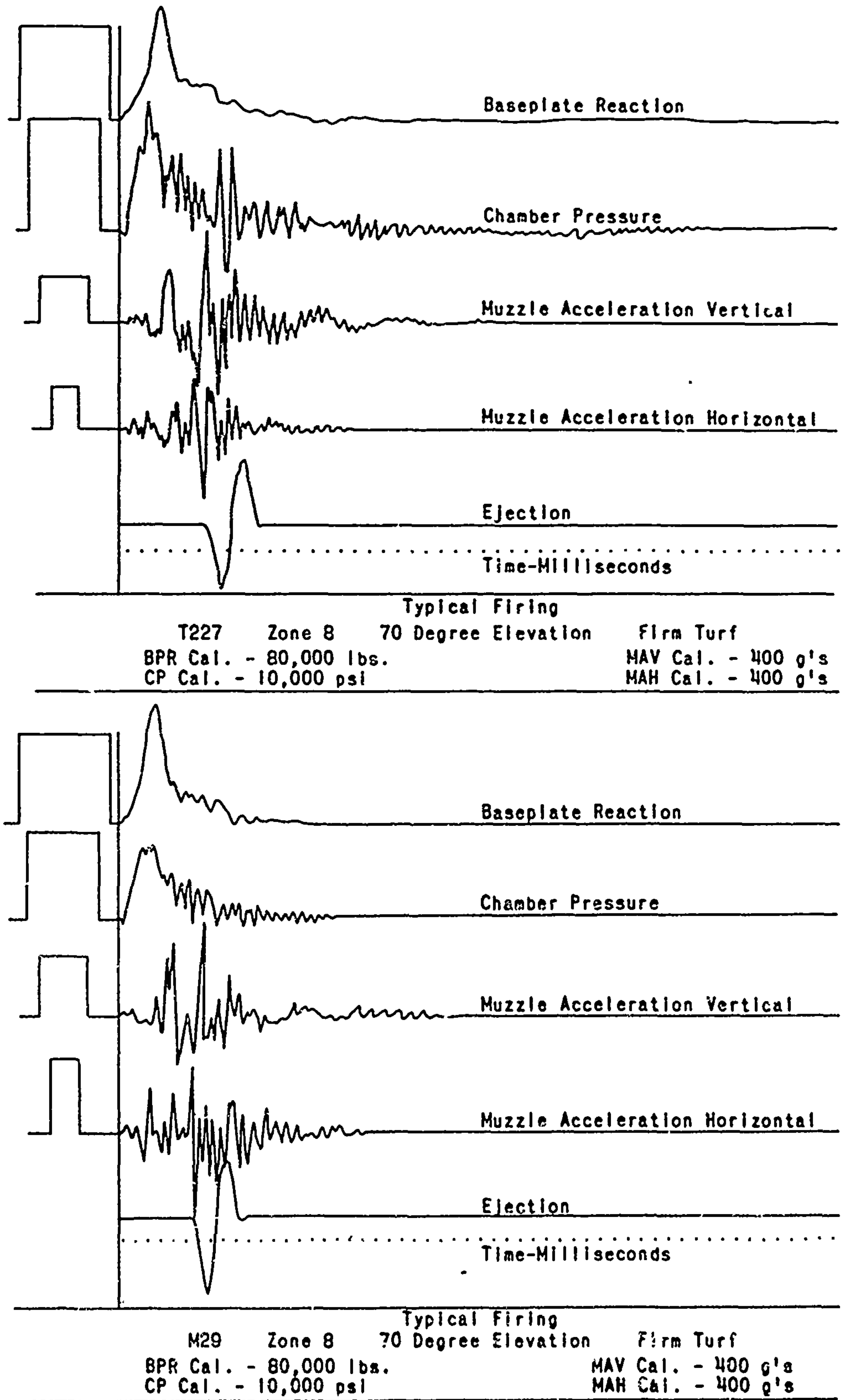


Figure 14. Typical Test Group I Firing Records.

TABLE I.

				B.P. Reaction (lbs F)		Chamber Pressure (psi)		Muzzle Acceleration Vertical Plane (g's)				Muzzle Acceleration Horizontal Plane (g's)				Time (seconds)		Muzzle Velocity (ft/sec)	
				M29	T227	M29	T227	M29	T227	M29	T227	M29	T227	M29	T227	M29	T227	M29	T227
Zone 5	70	FT	CEN	52,647	43,799	6,833	6,478	422	638	372	790	443	798	375	680	.0093	.0093	665	658
			XL		48,394		7,991		623		510		440		735		.0115		661
		SL	CEN	67,673	69,427	6,124	5,993	752	1,013	732	774	598	636	652	909	.0090	.0087	677	663
			XL	77,330	54,783	5,959	6,636	734	936	858	756	691	692	739	600	.0091	.0092	681	672
	55	FT	CEN	74,703	43,312	6,267	7,497	566	684	390	499	412	571	243	661	.0093	.0092	683	667
			XL		42,355		6,868		794		614		613		845		.0092		666
		SL	CEN	56,378	47,360	6,270	6,230	840	876	702	618	605	646	713	860	.0089	.0093	685	688
			XL	61,054	50,376	6,980	6,763	824	756	728	604	605	552	621	748	.0089	.0092	686	683
	45	FT	CEN	48,230	28,610	5,991	7,006		674		581		729		704	.0088	.0091	684	673
			XL																
		SL	CEN		46,455		6,310		812		584		542		900		.0089		688
			XL		54,683		6,943		954		806		524		733		.0089		688
Zone 8	70	FT	CEN	107,924	88,608	9,317	9,420	489	839	463	784	371	642	329	540	.0082	.0080	782	774
			XL		72,303	9,940			556		604		600		707		.0103		769
		SL	CEN																
			XL																
	55	FT	CEN	84,260	62,844	9,036	9,487									.0079	.0078	781	766
			XL		64,445	8,833			754		566		436		922		.0079		771
		SL	CEN																
			XL																
	45	FT	CEN		46,985		10,705		633		588		611		794		.0078		765
			XL																
		SL	CEN																
			XL																
Zone 9	70	FT	CEN	123,154	106,143	12,553	10,313	552	719	457	717	317	621	354	605	.0074	.0075	830	819
			XL		117,215		11,856		536		677		658		541		.0110		813
		SL	CEN																
			XL																
	55	FT	CEN	93,093	76,849	10,332	12,615	336	636	297	500	301	622	400	515	.0074	.0073	827	809
			XL																
		SL	CEN																
			XL																
	45	FT	CEN		83,636		10,705		486		488		627		560		.0072		824
			XL																
		SL	CEN																
			XL																
M43A1 Zone 8	70°	FT	XL		54,667		7,820		116		160		152		144		.0075		811
Zone 11	70°	FT	XL		81,532		11,096		216		224		220		240		.0064		950

2. Baseplate Reaction Analysis

Several interesting observations are possible concerning the recorded baseplate reaction.

a. The data clearly indicate a reduction in baseplate reaction occurs with both mortars when fired at all conditions when the quadrant elevation is decreased. This is unquestionably due to the greater effective recoil stroke due to the baseplate skidding rearward some appreciable distance under these conditions.

b. The data clearly indicate that at all test conditions the baseplate reaction of the T227E2 is significantly less than for the M29. It is postulated that this is due to the lower recoiling mass of this mortar. This effect may mean that with the lighter tube and mount, an additional reduction in baseplate structure and weight is feasible. Considered from a different point of view, it may be possible to fire a greater number of rounds from an emplacement before the baseplate digs itself too far into the ground.

The objectives of Test Group 1 were to investigate the performance parameters of the basic mortar systems, M29 and T227, and to collect a basic body of performance data to which subsequent tests, which embodied additional variables, could be correlated.

The controlled variables which were actually incorporated into Test Group 1 were as follows:

Variables			
Baseplates	Canadian Forged Aluminum		
Mounts	M23A3	T64E2	
Tubes	M29	T227E2	
Zones	6	8	9
Elevations	45 degrees	55 degrees	70 degrees
Traverse	Center	Ex Left	
Soil	Sandy Loam	Firm Turf	

Test Key

	Mount/Tube	Round/Zone	Elevation/Traverse	Soil/Cant
Example	M23/M29	M362/8	70/Cen	SL/0

Data Sheet Key

BPR	Maximum baseplate reaction
CP	Maximum chamber pressure
MAVU	Maximum vertical muzzle acceleration upward
MAVD	Maximum vertical muzzle acceleration downward
MAHL	Maximum horizontal muzzle acceleration to the left
MAHR	Maximum horizontal muzzle acceleration to the right
ET	Time from ignition to time tail fins clear the muzzle
MV	Muzzle velocity

Test	Mount/Tube	Round/Zone	Elev./Trav	Soil/Cant	BPR (lbs)	CP (psi)	MAVU (g's)	MAVD (g's)	MAHL (g's)	MAHR (g's)	ET (ms)	Muz.Vel (fps)
1	M23/M29	M362/6	70/cen	FT/o	31,640	6,869	420	412	564	416	.0092	665
2	"	"	"	"	37,209	7,158	484	280	384	264	.0092	665
3	"	"	"	"	51,163	7,432	200	336	368	340	.0092	663
4	"	"	"	"	60,235	6,563	484	404	524	440	.0095	661
5	"	"	"	"	66,047	6,526	476	436	404	368	.0093	666
6	"	"	"	"	69,767	6,458	468	368	416	424	.0095	668
Average					52,647	6,833	422	372	443	375	.0093	665
7	M23/M29	M362/8	70/cen	FT/o	86,957	9,231	468	508	424	304	.0080	779
8	"	"	"	"	101,818	8,446	592	512	300	240	.0078	784
9	"	"	"	"		9,737	608	432	508	316	.0081	784
10	"	"	"	"	108,800	8,649	488	388	400	292	.0081	784
11	"	"	"	"	109,474	8,219	472	400	440	332	.0090	777
12	"	"	"	"	116,842	8,919					.0088	777
13	"	"	"	"	111,579	8,933	472	456	244	440	.0082	782
14	"	"	"	"	120,000	12,432	324	548	280	380	.0082	786
Average					107,924	9,317	489	463	371	329	.0082	782
15	M23/M29	M362/9	70/cen	FT/o	132,364	13,846			332	452	$\boxed{.0111}$	825
16	"	"	"	"	135,849	13,231	600	540	300	264	.0079	838
17	"	"	"	"	93,333	12,813	500	316	284	312	.0075	828
18	"	"	"	"	124,444		592	456	324	352	.0071	836
19	"	"	"	"	129,778	10,317	516	516	344	392	.0071	825 [a]
Average					123,154	12,553	552	457	317	354	.0074	830

[a] Vertical accelerometer failed.

Test	Mount/Tube	Round/Zone	Elev/Trav	Soil/Cant	BPR (lbs)	CP (psi)	MAVU (g's)	MAVD (g's)	MAHL (g's)	MAHR (g's)	Time (ms)	MuzVel (fps)
20	M23/M29	M362/6	55/cen	FT/o	62,745	5,810					.0090	687
21	"	"	"	"	71,012	5,876	540	336	244	256	.0091	687
22	"	"	"	"	75,200	5,834	592	400	336	212	.0091	682
23	"	"	"	"	74,400	6,907	680	400	324	204	.0095	682
24	"	"	"	"	76,800	6,875	456	516	832	276	.0092	683
25	"	"	"	"	80,800	6,146					.0105	685
26	"	"	"	"	79,184	6,412	564	300	324	268	.0090	678
Average					74,305	6,267	566	390	412	243	.0093	683
27	M23/M29	M362/8	55/cen	FT/o	104,490	8,631	.146 in[a]		.093 in[a]		.0079	784
28	"	"	"	"	65,965	9,221	.062 in[b]		.082 in[b]		.0079	782
29	"	"	"	"	80,000	9,221	.161 in[c]		.108 in[c]		.0080	779
30	"	"	"	"	82,759	9,221					.0079	779
31	"	"	"	"	88,276	9,221					.0079	777
32	"	"	"	"	84,068	8,701					.0079	786
Average					84,260	9,036					.0079	781
33	M23/M29	M362/9	55/cen	FT/o	96,552	10,790	452	440	280	380	.0073	828
34	"	"	"	"	81,428	11,066	292	232	240	352	.0072	828
35	"	"	"	"	92,857	9,863	300	300	248	248	.0074	810
36	"	"	"	"	92,632	10,533	264	240	380	612	.0075	833
37	"	"	"	"	95,439	10,526	380	272	444	604	.0072	833[d]
38	"	"	"	"	99,649	9,211			216	208	.0075	830
Average					93,093	10,332	336	297	301	400	.0074	827
39	M23/M29	M362/6	45/cen	FT/o	44,286	6,000	668	408			.0088	683
40	"	"	"	"	52,174	5,982						685
Average					48,230	5,991	668	408			.0088	684

Muzzle displacement from original aiming point, at ejection

[a] Muz V Position at Eject—up 0.146 in; Muz H Position at Eject—left 0.093 in

[b] Muz V Position at Eject—up 0.062 in; Muz H Position at Eject—left 0.082 in

[c] Muz V Position at Eject—up 0.161 in; Muz H Position at Eject—left 0.108 in

[d] Horizontal Accelerometer failed.

Test	Mount / Tube	Round / Zone	Elev. / Trav.	Soil / Cant	BPR (lbs)	CP (psi)	MAVU (g's)	MAVD (g's)	MAHL (g's)	MAHR (g's)	TIME (ms)	MuzVel (fps)
41	T64 / T227	M362 / 6	70 / cen	FT / 0	38,835	7,627			456	484	.0092	661
42	"	"	"	"	46,602	7,373	452	524			.0095	661
43	"	"	"	"	57,476	8,547			536	432	.0095	653
44	"	"	"	"	60,769	8,291	480	544			.0105	666
45	"	"	"	"	70,680	7,949			564	448	.0092	663
46	"	"	"	"	67,810	7,214	448	376			.0093	665
Average					57,029	7,838	460	481	518	454	.0095	662
47	T64 / T227	M362 / 8	70 / cen	FT / 0	92,000	11,346			576	424	.0080	759
48	"	"	"	"	92,000	8,190	440	508			.0082	755
49	"	"	"	"	85,000	8,431			272	248	.0076	782
50	"	"	"	"	87,000	7,692	464	444			.0077	782
51	"	"	"	"	90,127	8,137			296	376	.0081	757
52	"	"	"	"	89,000	8,349	488	404			.0079	766
53	"	"	"	"	84,051	9,904					.0082	764
Average					88,454	8,864	464	452	381	349	.00796	766

Test	Mount/Tube	Round/Zone	Elév./Trav.	Soil/Cant	BPR (lbs)	CP (psi)	MAVU (g's)	MAVD (g's)	MAHL (g's)	MAHR (g's)	Time (ms)	MuzVel (fps)
54	T64/T227	M362/6	70/cen	FT/0	62,400	6,018	464	456	804	620	.0091	663
55	"	"	"	"	37,172	6,111	648	1,088	836	564	.0094	650
56	"	"	"	"	60,408	6,666	664	1,276	680	640	.0097	662
57	"	"	"	"	26,123	5,536	608	324	748	660	.0088	654
58	"	"	"	"	40,404	7,778					.0094	654
59	"	"	"	"	36,289	6,759	808	808	920	920	.0093	662
Average					43,799	6,473	638	790	798	680	.0093	658
60	T64/T227	M362/8	70/cen	FT/0	81,000	8,830	800	600	640	320	.0084	778
61	"	"	"	"	55,000	8,723	672				.0081	766
62	"	"	"	"	92,631	10,000	884	972	488	340	.0078	782
63	"	"	"	"	94,814	9,785	808	656	520	724	.0078	778
64	"	"	"	"	98,000	9,335	936	976	620	776	.0083	764
65	"	"	"	"	104,000	9,785	800	720	660	512	.0078	778
66	"	"	"	"	94,814	9,463	976		924	572	.0079	
Average					88,608	9,420	839	784	642	540	.0080	774
67	T64/T227	M362/9	70/cen	FT/0	108,751	10,625	896	1,056	800	384	.0077	806
68	"	"	"	"	117,447	10,317	920	584	592	720	.0079	826
69A	"	"	"	"	98,246	10,000	752	628	464	512	.0074	813
70	"	"	"	"	108,148	10,317	528	624	648	780	.0075	833
71	"	"	"	"	106,667	10,492	656	928	736	864	.0075	826
72	"	"	"	"	90,182	10,635	624	448	480	528	.0075	811
73	"	"	"	"	118,571	10,925	656	752	632	448	.0071	828
Average					106,143	10,313	719	717	621	605	.0075	819

Test	Mount/Tube	Round/Zone	Elev./Trav	Soil/Cant	BPR (lbs)	CP (psi)	MAVU (g's)	MAVD (g's)	MAHL (g's)	MAHR (g's)	Time (ms)	MuzVel (fps)
74	T64/T227	M362/6	55/cen	FT/0	63,297	8,721	516	1,008	604	368	.0090	661
75	"	"	"	"	40,000	7,791	788	352	544	536	.009	670
76	"	"	"	"	39,111	8,000	916	360	580	904	.0094	665
77	"	"	"	"	37,753	8,588	480	468	636	692	.0093	678
78	"	"	"	"	47,111	5,647	780	400	664	972	.0091	665
79	"	"	"	"	44,445	6,235	628	408	400	492	.0093	661
Average					45,312	7,497	684	[illegible]	571	611	.0092	667
80	T64/T227	M362/8	55/cen	FT/0	49,143	8,824					.0078	777
81	"	"	"	"	65,143	9,131					.0078	764
82	"	"	"	"	69,565	9,265					.0079	766
83	"	"	"	"	51,765	9,104					.0081	759
84	"	"	"	"	67,246	10,746					.0078	766
85	"	"	"	"	74,203	9,851					.0079	761
Average					62,844	9,487					.0078	766
86	T64/T227	M362/9	55/cen	FT/0	86,857	12,985	760	572	684	428	.0071	810
87	"	"	"	"	84,638	11,343	640	520	640	740	.0075	813
88	"	"	"	"	62,857	13,044	472	436	480	464	.0072	803
89	"	"	"	"	73,043	13,088	672	472	684	428	.0075	810[a]
Average					76,849	12,615	636	500	622	515	.0073	809

[a]Rotating sight bracket mount failed.

Test	Mount/Tube	Round/Zone	Elev/Trav	Soil/Cant	BPR (lbs)	CP (psi)	MAVU (g's)	MAVD (g's)	MAHL (g's)	MAHR (g's)	Time (ms)	MuzVel (fps)
90	T64/T227	M362/6	45/cen	FT/0	13,333	7,843	-656	304	592	648	.0089	668
91	"	"	"	"	55,000	7,255	+600	724	780	704	.0091	668
92	"	"	"	"	36,667	7,426	288*	188*	144*	172*	.0088	667
93	"	"	"	"	40,421	7,549	244*	264*	240*	204*	0093	665
94	"	"	"	"	13,474	5,490	420*	292*	296*	296*	.0092	682
95	"	"	"	"	12,766	6,471	768	716	816	760	.0091	687
Average					28,610	7,006	674	581	729	704	.0091	673
96	T64/T227	M362/8	45/cen	FT/0	32,500	8,733	756	660	636	800	.0080	778
97	"	"	"	"	40,000	11,857	+604	524	656	900	.0078	762
98	"	"	"	"	49,057	10,282	440*	356*	+192*	236*	.0078	766
99	"	"	"	"	49,812	9,527	280*	200*	128*	272*	.0078	766
100	"	"	"	"	51,636	8,572	360*	280*	+312*	284*	.0076	759
101	"	"	"	"	58,909	8,714	540	580	540	684	.0078	759
Average					46,985	9,640	633	588	+611	794	.0078	765
102	T64/T227	M362/9	45/cen	FT/0	58,667	10,938	532	612	668	540	.0072	800
103	"	"	"	"	96,180	12,656	424	440	612	484	.0072	810
104	"	"	"	"	89,888	12,188	504	412	600	656	.0073	828
105	"	"	"	"	76,405	10,156	564*	548*	164*	248*	.0070	825
106	"	"	"	"	95,281	9,231	428*	468*	240*	200*	.0072	854
107	"	"	"	"	85,394	9,063	520*	520*	240*	256*	.0075	828
Average					83,636	10,705	486	488	627	560	.0072	824

*Base of barrel—not included in averages.

Test	Mount/Tube	Round/Zone	Elev/Trav	Soil/Cant	BPR (lbs)	CP (psi)	MAVU (g's)	MAVD (g's)	MAHR (g's)	MAHL (g's)	Time (ms)	MuzVel (fps)
108	T64/T227	M362/6	70/XL	FT/0		6,042	412	384	200	184	.0108	663
109	"	"	"	"	No record							
110	"	"	"	"	51,948	8,532	712	812	524	924	.0110	650
111	"	"	"	"	39,588	8,965	508	356	376	800	.0104	663
112	"	"	"	"	32,653	7,241	700	600	452	784	.0151	665
113	"	"	"	"	69,388	9,186	784	400	652	984	.0103	663
Average					48,394	7,991	623	510	440	735	.0115	661
114	T64/T227	M362/8	70/XL	FT/0	66,667	13,381	712	700	528	940	.0079	778
115	"	"	"	"	76,757	10,159	656	500	696	720	.0107	766
116	"	"	"	"	67,945	8,226	456	568	600	600	.0078	762
117	"	"	"	"	63,562	9,667	512	712	504	640	.0154	766
118	"	"	"	"	77,778	8,871	428	512	612	680	.0124	762
119	"	"	"	"	81,111	9,334	576	636	664	664	.0080	778
Average					72,303	9,940	556	604	600	707	.0103	769
120	T64/T227	M362/9	70/XL	FT/0	102,500	10,556	664	904	536	688	.0131	826
121	"	"	"	"	110,000	11,445	744	600	548	688	.0078	813
122	"	"	"	"	109,206	11,482	372	480	768	540	.0083	808
123	"	"	"	"	114,286	14,047	612	864	688	524	.0172	806
124	"	"	"	"	118,709	11,698	664		740	540	.0146	803
125	"	"	"	"	132,903	11,321	400	520	864	412	.0082	806
126	"	"	"	"	132,903	12,408	300	712	508	400	.0076	828
Average					117,215	11,856	536	677	658	641	.0110	813

Test	Mount/Tube	Round/Zone	Elev./Trav.	Soil/Cant	BPR (lbs)	CP (psi)	MAVU (g's)	MAVD (g's)	MAHL (g's)	MAHR (g's)	Time (ms)	MuzVel (fps)
127	T64/T227	M43/8	70/XL	FT/0	52,211	8,077	116	160	156	156	.0075	810
128	"	"	"	"	57,143	7,564			148	132	.0075	813[a]
Average					54,677	7,820	116	160	152	144	.0075	811
129	T64/T227	M43/11	70/XL	FT/0	80,987	12,031	216	224			.0065	949
130	"	"	"	"	82,078	10,161			220	240	.0063	952
Average					81,532	11,096	216	224	220	240	.0064	950
131	T64/T227	M362/6	55/XL	FT/0	52,473	7,710			692	860	.0091	666
132	"	"	"	"	52,445	7,041	848	508			.0091	666
133	"	"	"	"	28,387	5,714			724	904	.0095	665
134	"	"	"	"	48,172	7,127	836	804			.0092	665
135	"	"	"	"	29,247	7,041			424	772	.0093	665
136	"	"	"	"	43,404	6,531	700	532			.0093	668
Average					42,355	6,868	794	614	613	845	.0092	666
137	T64/T227	M362/8	55/XL	FT/0	60,952	9,014	496	532			.0080	764
138	"	"	"	"	64,000	8,733			440	960	.0081	764
139	"	"	"	"	69,769	9,014	1,012	600			.0081	777
140	"	"	"	"	63,059	8,572			432	884	.0077	779
Average					64,445	8,833	754	566	436	922	.0079	771

[a]Vertical accelerometer failed.

Test	Mount/Tube	Round/Zone	Elev./Trav.	Soil/Cant	BPR (lbs)	CP (psi)	MAVU (g's)	MAVD (g's)	MAHL (g's)	MAHR (g's)	Time (ms)	MuzVel (fps)
145	T64/T227	M362/6	70/cen	SL/0	97,273		952	876	808	664	.0089	668
146	"	"	"	"	63,030	5,439	760	824	424	888	.0091	661
147	"	"	"	"	70,154	6,429	1,200	652	760	952	.0092	661
148	"	"	"	"	64,000	5,857	1,000	584	384	876	.0089	666
149	"	"	"	"	63,158	6,024	1,200	744	676	984	.0067	663
150	"	"	"	"	58,947	6,219	920	1,120	800	1,012	.0093	661
Average					69,427.0	5,993.6	1,013	774	636	909	.00868	663.3
151	T64/T227	M362/6	70/XL	SL/0	62,703	5,803	1,064	624	604	992	.0094	670
152	"	"	"	"	74,595	6,296	868	716	372	412	.0091	668
153	"	"	"	"	52,973	7,000	728	744	772	652	.0088	682
154	"	"	"	"	48,649	6,250	940	640	640	480	.0089	666
155	"	"	"	"	47,123	7,180	1,212	856	688	728	.0088	680
156	"	"	"	"	55,135	5,875	880	700	824	716	.0103	670
157	"	"	"	"	49,315	7,375	1,056	768	712	528	.0092	666
158	"	"	"	"	47,778	7,309	868	884	840	688	.0092	678
Average					54,783.9	6,636.0	936	756	692	600	.00921	672.5
159	T64/T227	M362/6	55/cen	SL/0	38,889	6,029	1,084	584	456	1,000	.0094	683
160	"	"	"	"	53,333	5,844	968	568	744	880	.0093	687
161	"	"	"	"	53,333	6,154	612	628	696	740	.0095	680
162	"	"	"	"	47,442	6,129	576	480	640	1,000	.0097	716
163	"	"	"	"	No Record		868	868	912	612		
164	"	"	"	"	46,512	6,882	1,012	600			.0091	683
165	"	"	"	"	44,651	6,344	1,012	600	428	932	.0091	683
Average					47,360.0	6,230.3	876	618	646	860	.00935	688.7

Test	Mount/Tube	Round/Zone	Elev/Trav	Soil/Cant	BPR (lbs)	CP (psi)	MAVU (g's)	MAVD (g's)	MAHL (g's)	MAHR (g's)	Time (ms)	MuzVel (fps)
166	T64/T227	M362/6	55/XL	SL/0	50,575	6,848	668	712	456	856	.0092	683
167	"	"	"	"	45,600	6,800	720		684	776	.0092	670
168	"	"	"	"	48,000	7,426	808	520	504	768	.0093	683
169	"	"	"	"	48,485	6,337	1012	640	628	568	.0093	683
170	"	"	"	"	56,800	6,733	728	560	588	544	.0092	682
171	"	"	"	"	52,800	6,436	600	588	452	776	.0091	698
Average					50,376.7	6,763.3	756	604	552	748	.00922	683.2
172	T64/T227	M362/6	45/cen	SL/0	40,800	7,500	656	500	440	1008	.0089	683
173	"	"	"	"	44,800	6,436	520	540	500	696	.0093	683
174	"	"	"	"	46,869	5,784	860	600	612	1024	.0091	680
175	"	"	"	"	43,636	6,200	940	488	572	952	.0088	683
176	"	"	"	"	48,485	5,941	1040	760	468	860	.0090	720
177	"	"	"	"	54,141	6,000	860	620	656	860	.0088	680
Average					46,455.2	6,310.2	812	584	542	900	.00898	688.2
178	T64/T227	M362/6	45/XL	SL/0	52,800	6,078	700	588	368	656	.0089	
179	"	"	"	"	55,758	6,436					.0089	683
180	"	"	"	"	55,758	6,700	800	948	460	1024	.0088	685
181	"	"	"	"	52,525	6,700					.0088	
182	"	"	"	"	54,694	6,869	1168	884	756	628	.0080	685
183	"	"	"	"	56,566	8,877	1148		512	624	.0090	698
Average					54,683.5	6,943.3	954	806	524	733	.0089	687.8

Test	Mount/Tube	Round/Zone	Elev/Trav	Soil/Cant	BPR (lbs)	CP (psi)	MAVU (g's)	MAVD (g's)	MAHL (g's)	MAHR (g's)	Time (ms)	MuzVel (fps)
184	M23/M29	M362/6	70/cen	SL/0	59,048	6,585	780	588	408	388	.0091	683
185	"	"	"	"	67,470	6,420					.0088	683
186	"	"	"	"	69,398	6,050	680	892	788	788	.0091	665
187	"	"	"	"	71,326	5,444	908			800	.0089	666
188	"	"	"	"	68,434	5,843	816	912	780	704	.0093	683
189	"	"	"	"	70,362	6,405	576	576	416	580	.0088	682
Average					67,673.0	6,124.5	752	732	598	652	.00900	677.0
190	M23/M29	M362/6	70/XL	SL/0	80,000	6,129	764	832	508	808	.0091	678
191	"	"	"	"	78,222	6,344	648	992	788	688	.0090	682
192	"	"	"	"	77,333	5,761	692	816	704	640	.0093	685
193	"	"	"	"	70,222	5,495	780	764	676	772	.0092	678
194	"	"	"	"	78,203	6,264	852	824	780	772	.0089	680
195	"	"	"	"	80,000	5,761	636	924		744	.0091	682
Average					77,330.0	5,959.0	734	858	691	739	.0091	680.8
196	M23/M29	M362/6	55/cen	SL/0		5,652	644	744	520	668	.0092	687
197	"	"	"	"		6,555	660	672	512	704	.0089	680
198	"	"	"	"	55,258	6,024	1044	724	612	884	.0089	701
199	"	"	"	"	56,666	6,463	852	744	504	720	.0088	682
200	"	"	"	"	55,258	6,098	900	644	808	504	.0090	682
201	"	"	"	"	58,333	6,829	944	688	676	800	.0089	682
Average					56,378.8	6,270.2	840	702	605	713	.00895	685.7

Test	Mount/Tube	Round/Zone	Elev/Trav	Soil/Cant	BPR (lbs)	CP (psi)	MAVU (g's)	MAVD (g's)	MAHL (g's)	MAHR (g's)	Time (ms)	MuzVel (fps)
202	M23 M29	M362 6	55 XL	SL 0	61,177	8,025	780	1060	816	736	.0089	701
203	"	"	"	"	55,530	6,951	952	680	512	684	.0091	687
204	"	"	"	"	62,325		908	636	528	624	.0091	678
205	"	"	"	"	64,941	6,962	816	696	880	488	.0087	683
206	"	"	"	"	60,236	6,543	672	720	444	540	.0091	680
207	"	"	"	"	62,118	6,420	816	576	452	656	.0089	[a]
Average					61,054.5	6,980.2	824	728	605	621	.00896	685.8

[a] Horizontal accelerometer failed.

Test Group 3

Of those test groups included in the original program plan, only test group three was completed. This was primarily because this test group did not require measurement of the muzzle motion phenomena as a principal requirement.

As was indicated in the discussion of base plugs, the baseplate reaction data which was recorded during this test group was invalidated due to the gross bending of the base plugs while firing from emplacements on concrete.

The objectives of test group three were to study the behavior of the Mortars M29 and T227 over a spectrum of 16 controlled variables to investigate possible unsymmetrical loading of the bipod legs for two conditions of baseplate cant. In addition, the direction and magnitude of accelerations which appear at the center of gravity of the sight under these conditions were to be monitored.

The controlled variables incorporated into test group three were as follows:

Variables

Baseplates	Canadian Forged Aluminum	
Mounts	M23A3	T64E2
Tubes	M29	T227E2
Zones	8	9
Elevations	45 degrees	70 degrees
Traverse	Center	
Soil	Concrete	Sandy loam
Baseplate cant	Right edge + 5 degrees	Forward edge - 5 degrees

Test Key

	Mount/Tube	Round/Zone	Elevation/Traverse	Soil/B.P.Cant
Example	M23/M29	M362/8	70/Cen.	SL/-5

Data Sheet Key

CP	Maximum chamber pressure
SATL	Maximum transverse sight acceleration to the left
SATR	Maximum transverse sight acceleration to the right
SALR	Maximum longitudinal sight acceleration rearward
SALF	Maximum longitudinal sight acceleration forward
LBL	Maximum dynamic load appearing in the left bipod leg
RBL	Maximum dynamic load appearing in the right bipod leg
ET	Time from ignition to time tail fins clear the muzzle
MV	Muzzle velocity

Test	Mount/Tube	Round/Zone	Elev/Trav	Soil/Cant	CP (psi)	SATL (g's)	SATR (g's)	SALR (g's)	SALF (g's)	LBL (lbs)	RBL (lbs)	Time (ms)	MuzVel (fps)
208	M23/M29	M362/8	70/cen	Con/-5		160	153			60	43	7.6	803
209	"	"	"	"		264	225			109	35	7.7	786
210	"	"	"	"		167	159			100	35	8.0	764
211	"	"	"	"				59	79	69	55	7.7	779
212	"	"	"	"				71	83	80	79	8.0	784
213	"	"	"	"				122	146	84	53	7.7	784
214	"	"	"	"				97	105	66	102	7.6	803
Average						197	179	87	103	81	57	7.7	786
215	M23/M29	M362/9	70/cen	Con/-5				157	125	34	128	7.3	830
216	"	"	"	"				155	126	47	102	7.2	838
217	"	"	"	"				85	98	70	92	7.1	835
218	"	"	"	"		181	132			53	92	7.3	833
219	"	"	"	"		329	206			57	102	6.9	833
220	"	"	"	"		133	154			100	75	7.3	828
Average						214	164	132	116	60	99	7.1	833
221	T64/T227	M362/8	70/cen	Con/-5		90	73			36	47	7.4	789
222	"	"	"	"		130	100			42	35	7.7	777
223						265	204			42	38	7.7	784
224						158	167			56	50	7.9	777
225								70	66	46	57	7.7	784
226								101	80	48	43	8.0	782
227								92	88	46	44	7.6	784
Average						161	136	88	78	45	45	7.7	782
228	T64/T227	M362/9	70/cen	Con/-5				84	96	42	49	7.0	833
229	"	"	"	"				80	51	41	18	7.3	830
230	"	"	"	"				67	63	25	35	7.3	833
231	"	"	"	"				127	106	64	52	7.0	835
232	"	"	"	"		187	106			64	50	7.1	833
233	"	"	"	"		106	63			58	63	7.1	835
234	"	"	"	"		210	210			94	63	7.3	828
Average						168	126	90	79	55	47	7.1	832

Test	Mount/Tube	Round/Zone	Elev/Trav	Soil/Cant	CP (psi)	SATL (g's)	SATR (g's)	SALR (g's)	SALF (g's)	LBL (lbs)	RBL (lbs)	Time (ms)	MuzVel (fps)
235	T64/T227	M362/8	45/cen	Con/-5		282	147			78	65	7.5	779
236	"	"	"	"		172	143			87	67	7.5	784
237	"	"	"	"		219	143			137	83	7.4	782
238	"	"	"	"				123	119	120	82	7.5	784
239	"	"	"	"				44	31	74	61	7.1	786
240	"	"	"	"				110	92	208	200	8.3	803
Average						224	144	92	80	117	93	7.5	786
242	T64/T227	M362/9	45/cen	Con/-5				82	20	162	134	7.1	825
243	"	"	"	"				109	147	142	139	7.2	825
244	"	"	"	"				54	77	97	84	7.4	825
245	"	"	"	"		193	162			137	156	7.3	836
246	"	"	"	"		314	202			252	215	7.3	860
247	"	"	"	"		155	106			131	94	7.1	833
Average						221	157	82	115	154	137	7.2	834
248	M23/M29	M362/8	45/cen	Con/-5		212	196			90	62	7.8	784
249	"	"	"	"		172	224			132	73	7.6	800
250	"	"	"	"		252	276			151	100	8.1	805
251	"	"	"	"				116	172	176	75	7.9	786
252	"	"	"	"				140	212	162	100	8.0	786
253	"	"	"	"				158	162	177	99	7.7	784
Average						212	232	138	182	148	85	7.9	791
254	M23/M29	M362/9	45/cen	Con/-5				245	261	431	247	7.5	854
255	"	"	"	"				159	269	172	187	6.9	886
256	"	"	"	"				117	154	97	100	7.3	852
257	"	"	"	"		206	92			393	109	7.3	836
258	"	"	"	"		165	210			142	131	7.4	833
259	"	"	"	"		206	206			148	125	7.1	828
Average						190	169	174	228	231	150	7.3	848

Test	Mount/Tube	Round/Zone	Elev/Trav	Soil/Cant	CP (psi)	SATL (g's)	SATR (g's)	SALR (g's)	SALF (g's)	LBL (lbs)	RBL (lbs)	Time (ms)	MuzVel (fps)
260	M23/M29	M362/8	70/cen	Con/R5		161	183			317	158	7.7	786
261	"	"	"	"		183	174			163	40	7.9	784
262	"	"	"	"		126	117			92	84	7.8	803
263	"	"	"	"		231	117			100	51	7.9	789
264	"	"	"	"				155	133	106	87	7.5	786
265	"	"	"	"				242	286	129	42	8.2	782
Average						175	148	199	210	151	77	7.8	788
266	M23/M29	M362/9	70/cen	Con/R5				120	181	98	44	7.3	836
267	"	"	"	"				187	187	119	53	7.5	833
268	"	"	"	"				219	310	104	55	6.3	883
269	"	"	"	"		280	211			92	68	7.3	833
270	"	"	"	"		172	116			67	37	7.4	883
271	"	"	"	"		239	211			71	52	7.3	830
Average						230	179	175	196	92	52	7.2	849
272	T64/T227	M362/8	70/cen	Con/R5	7,404	234	360			215	225	7.8	757
273	"	"	"	"	7,647	309	239			66	75	7.7	782
274	"	"	"	"	7,980	171	122			117	108	7.8	777
275	"	"	"	"	7,879			90	82	127	140	7.7	779
276	"	"	"	"	8,081			82	106	71	77	7.9	777
277	"	"	"	"	8,081			82	82	86	86	7.5	782
Average					7,845	238	240	84	90	114	118	7.7	776
278	T64/T227	M362/9	70/cen	Con/R5	9,175			83	58	67	58	7.5	833
279	"	"	"	"	9,175			133	117	96	112	7.2	854
280	"	"	"	"	9,167			74	82	94	101	7.2	835
281	"	"	"	"	8,889	133	148			101	108	7.1	825
282	"	"	"	"	9,627	262	262			126	95	7.1	830
283	"	"	"	"	9,052	208	177			148	158	7.3	830
Average					9,104	201	196	97	86	105	105	7.2	835

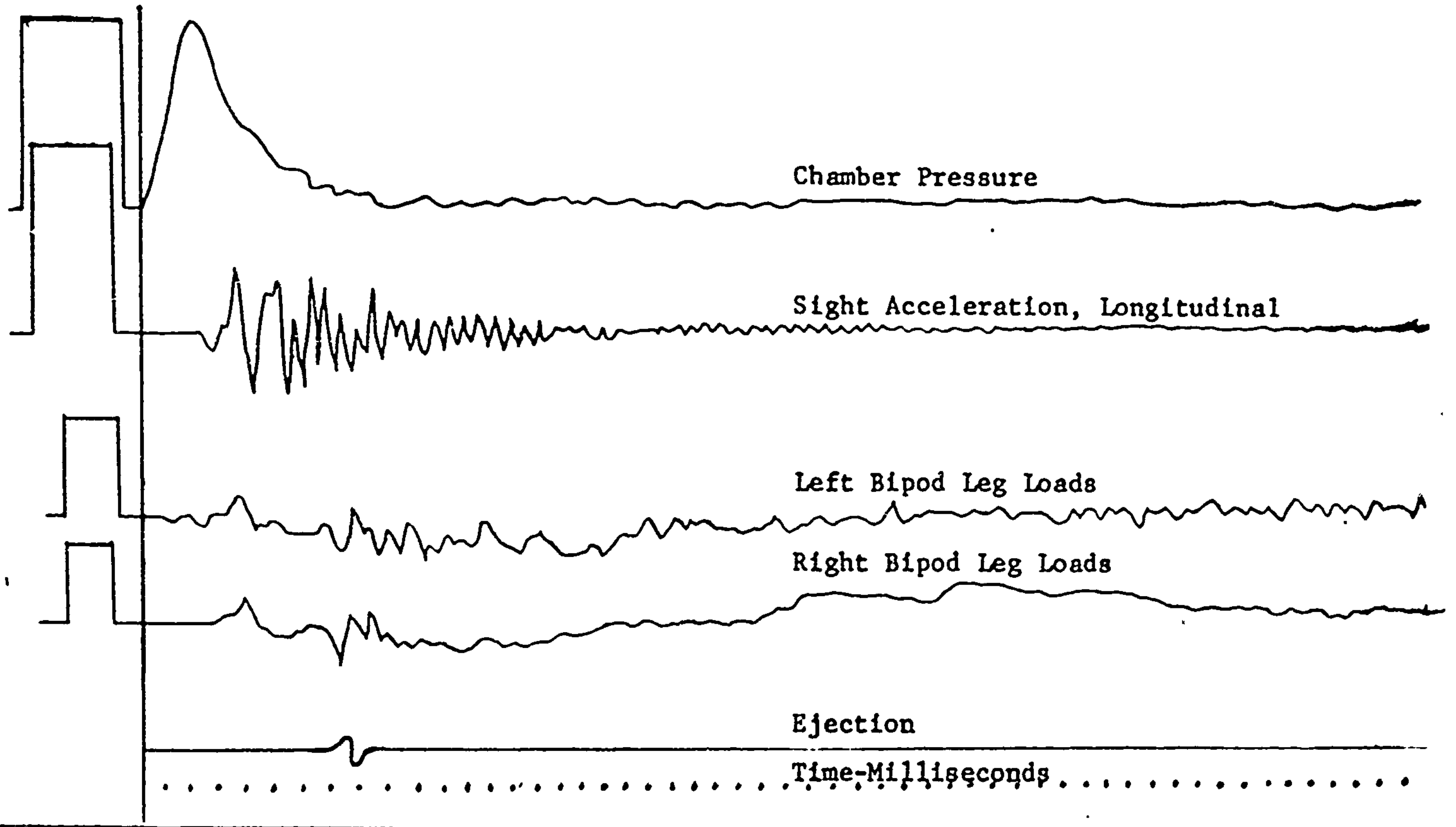
Test	Mount/Tube	Round/Zone	Elev/Trav	Soil/Cant	CP (psi)	SATL (g's)	SATR (g's)	SALR (g's)	SALF (g's)	LBL (lbs)	RBL (lbs)	Time (ms)	MuzVel (fps)
284	T64/T227	M362/8	45/cen	Con/R5	7,935	243	220			124	137	7.5	---
285	"	"	"	"	8,065	169	177			43	43	7.5	828
286	"	"	"	"	8,191	146	115			127	107	7.5	800
287	"	"	"	"	7,635			62	62	126	104	7.5	789
288	"	"	"	"	7,420			77	92	92	118	7.7	803
289	"	"	"	"	8,261			173	126	200	163	7.6	784
Average					7,918	186	171	104	93	119	112	7.6	801
290	T64/T227	M362/9	45/cen	Con/R5	7,957			78	133	133	169	7.3	833
291	"	"	"	"	9,783			102	118	189	172	6.9	833
292	"	"	"	"	10,349			157	165	277	209	7.2	828
293	"	"	"	"	9,783	102	94			253	324	7.1	830
294	"	"	"	"	9,780	196	94			450	371	7.1	833
295	"	"	"	"	9,551	239	196			515	473	7.3	854
Average					9,534	186	128	112	139	303	286	7.2	835
296	M23/M29	M362/8	45/cen	Con/R5	8,216	188	259			144	173	7.5	782
297	"	"	"	"	8,153	346	262			216	123	7.7	779
298	"	"	"	"	7,957	254	208			94	127	7.7	766
299	"	"	"	"	7,957			368	267	196	123	7.5	777
300	"	"	"	"	7,935			314	267	167	100	7.8	784
301	"	"	"	"	8,261			204	165	132	127	7.8	782
Average					8,087	263	243	295	233	158	129	7.7	778
302	M23/M29	M362/9	45/cen	Con/R5	9,341			280	360	86	127	7.1	830
303	"	"	"	"	8,913			176	280	148	131	7.2	---
304	"	"	"	"	9,451			232	352	180	125	7.3	830
305	"	"	"	"	9,348	290	235			108	104	7.2	825
306	"	"	"	"	9,348	512	400			145	169	7.1	813
307	"	"	"	"	8,817	248	272			124	83	7.2	830
Average					9,203	350	302	229	331	132	123	7.2	825

Test	Mount/Tube	Round/Zone	Elev/Trav	Soil/Cant	CP (psi)	SATL (g's)	SATR (g's)	SALR (g's)	SALF (g's)	LBL (lbs)	RBL (lbs)	Time (ms)	MuzVel (fps)
308	M23/M29	M362/8	70/cen	SL/-5	7,693	300	269			379	371	7.7	761
309	"	"	"	"	7,800	290	267			340	364	7.8	764
310	"	"	"	"	7,778	267	220			363	441	7.9	757
311	"	"	"	"	-----			188	180	396	388	7.7	784
312	"	"	"	"	8,384			160	144	288	267	7.6	782
313	"	"	"	"	8,350			160	152	353	349	7.9	782
Average					8,001	286	252	169	159	353	363	7.8	772
314	M23/M29	M362/9	70/cen	SL/-5	9,286			128	80	281	165	6.6	810
315	"	"	"	"	9,381			225	300	374	387	7.1	813
316	"	"	"	"	9,484			150	158	320	285	7.3	825
317	"	"	"	"	9,684	235	209			348	289	7.2	833
318	"	"	"	"	9,584	67	50			187	182	7.0	829
319	"	"	"	"	9,570	158	183			291	276	7.1	830
Average					9,498	153	147	168	179	301	281	7.1	833
320	M23/M29	M362/8	45/cen	SL/-5	8,453	325	183			68	751	7.7	---
321	"	"	"	"	8,737	204	272			55	38	7.6	803
322	"	"	"	"	8,526	247	230			131	67	7.7	782
323	"	"	"	"	8,817			221	136	26	98	7.8	782
324	"	"	"	"	8,805			293	231	64	67	7.6	787
325	"	"	"	"	8,444			153	102	70	70	8.0	826
Average					8,630	259	228	222	156	69	182	7.7	796
326	M23/M29	M362/9	45/cen	SL/-5	9,892			244	200	107	129	7.7	836
327	"	"	"	"	9,779			165	78	120	40	7.8	833
328	"	"	"	"	10,116			191	127	153	157	7.4	828
329	"	"	"	"	10,116	282	273			130	156	7.3	852
330	"	"	"	"	10,471	270	223			67	148	7.1	836
331	"	"	"	"	10,000	140	121			83	138	7.6	833
Average					10,062	231	206	200	135	110	128	7.4	836

Test	Mount/Tube	Round/Zone	Elev/Trav	Soil/Cant	CP (psi)	SATL (g's)	SATR (g's)	SALR (g's)	SALF (g's)	LBL (lbs)	RBL (lbs)	Time (ms)	MuzVel (fps)
332	M23/M29	M362/8	70/cen	SL/R5	8,889			361	353	513	463	7.6	778
333	"	"	"	"	8,788			125	172	242	250	7.5	778
334	"	"	"	"	8,877			251	345	227	252	7.9	780
335	"	"	"	"	8,877	274	204			250	145	7.9	782
336	"	"	"	"	8,687	267	235			220	125	8.2	784
337	"	"	"	"	9,072	248	232			240	200	7.5	782
Average					8,865	263	224	246	290	282	239	7.8	781
338	M23/M29	M362/9	70/cen	SL/R5	10,000	180	220			147	156	6.9	833
339	"	"	"	"	10,421	441	275			252	191	6.9	828
340	"	"	"	"	9,796	368	314			354	291	6.9	831
341	"	"	"	"	10,000			248	288	300	256	7.2	828
342	"	"	"	"	10,204			235	259	169	142	7.4	828
343	"	"	"	"	9,899			235	298	272	249	7.5	833
Average					10,053	330	270	239	282	249	214	7.1	830
344	T64/T227	M362/8	70/cen	SL/-5	8,660			80	70	354	409	7.9	778
345	"	"	"	"	8,646			113	92	369	357	7.8	764
346	"	"	"	"	8,526			92	72	361	289	7.7	784
347	"	"	"	"	8,485	284	254			416	373	7.6	760
348	"	"	"	"	8,469	208	232			310	244	7.6	---
349	"	"	"	"	8,646	192	168			371	350	7.8	778
Average					8,572	228	218	95	78	368	337	7.7	773
350	T64/T227	M362/9	70/cen	SL/-5	10,105	72	144			322	266	7.0	828
351	"	"	"	"	9,894	168	163			358	281	7.5	813
352	"	"	"	"	10,106	99	114			335	270	7.5	813
353	"	"	"	"	9,893			90	75	325	275	7.5	828
354	"	"	"	"	10,000			130	140	379	320	7.1	813
355	"	"	"	"	10,000			120	125	342	245	7.3	813
Average					10,000	113	140	113	113	344	276	7.3	818

Test	Mount/Tube	Round/Zone	Elev/Trav	Soil/Cant	CP (psi)	SATL (g's)	SATR (g's)	SALR (g's)	SALF (g's)	LBL (lbs)	RBL (lbs)	Time (ms)	MuzVel (fps)
356	T64/T227	M362/8	45/cen	SL/-5	8,866			85	105	86	88	7.8	784
357	"	"	"	"	8,673			163	155	95	97	7.9	778
358	"	"	"	"	8,485			93	151	59	108	7.9	811
359	"	"	"	"	8,788	89	54			68	115	7.8	806
360	"	"	"	"	8,775	66	47			51	61	7.6	808
361	"	"	"	"	8,667	125	63			90	125	7.7	828
Average					8,709	93	55	114	137	75	99	7.8	803
362	T64/T227	M362/9	45/cen	SL/-5	10,000	86	55			63	54	7.4	860
363	"	"	"	"	9,694	63	86			95	59	7.3	855
364	"	"	"	"	9,794	75	55			72		---	852
365	"	"	"	"	10,309			87	40	94	86	7.4	833
366	"	"	"	"	10,000			91	71	101	56	7.3	858
367	"	"	"	"	10,103			66	47	114	59	7.4	852
Average					9,983	75	65	81	53	90	64	7.3	852
368	T64/T227	M362/8	45/cen	SL/R5	11,619	138	155			91	63	7.5	782
369	"	"	"	"	8,586	78	58			75	75	7.7	784
370	"	"	"	"	8,400	101	130			95	73	7.5	803
371	"	"	"	"	8,830			80	70	107	164	7.8	778
372	"	"	"	"	8,510			65	45	92	70	7.7	801
373	"	"	"	"	8,201			76	56	63	122	7.6	784
Average					9,038	106	114	74	57	87	95	7.6	789
374	T64/T227	M362/9	45/cen	SL/R5	10,110			42	42	47	49	7.1	831
375	"	"	"	"	10,606			69	63	115	118	6.7	831
376	"	"	"	"	10,000			88	38	85	97	6.9	831
377	"	"	"	"	10,631	110	164			47	84	6.9	813
378	"	"	"	"	10,306	88	104			55	64	7.2	828
379	"	"	"	"	10,408	158	130			72	77	7.1	---
Average					10,344	118	133	66	48	70	81	7.0	827

Test	Mount/Tube	Round/Zone	Elev/Trav	Soil/Cant	CP (psi)	SATL (g's)	SATR (g's)	SALR (g's)	SALF (g's)	LBL (lbs)	RBL (lbs)	Time (ms)	MuzVel (fps)
380	T64/T227	M362/8	70/cen	SL/R5	8,788	400	197			409	273	7.4	782
381	"	"	"	"	8,750	79	133			293	156	7.8	784
382	"	"	"	"	8,646	152	152			410	254	7.6	766
383	"	"	"	"	8,660			78	66	434	143	7.7	778
384	"	"	"	"	8,646			73	56	382	177	7.9	782
385	"	"	"	"	8,830			74	57	348	191	7.7	780
Average					8,720	210	161	75	60	379	199	7.7	779
386	T64/T227	M362/9	70/cen	SL/R5	10,204			103	69	456	238	7.2	833
387	"	"	"	"	10,306			97	91	414	260	7.3	833
388	"	"	"	"	10,101			131	143	355	209	7.3	813
389	"	"	"	"	10,306	120	103			328	186	7.0	826
390	"	"	"	"	10,101	63	91			312	200	7.1	831
391	"	"	"	"	10,000	154	211			316	171	7.4	813
Average					10,169	112	135	110	101	364	211	7.2	825
392	M23/M29	M362/8	45/cen	SL/R5	9,584	263	202			94	139	7.6	789
393	"	"	"	"	10,327	149	160			54	117	7.7	855
394	"	"	"	"	9,278	235	160			57	21	7.7	806
395	"	"	"	"	9,670			250	278	83	85	7.7	784
396	"	"	"	"	10,220			186	170	100	107	7.7	782
397	"	"	"	"	9,789			176	149	73	83	7.5	780
Average					9,811	216	174	204	199	77	81	7.7	799
398	M23/M29	M362/9	45/cen	SL/R5	11,170			183	114	208	64	7.2	828
399	"	"	"	"	10,947			300	200	71	79	7.0	836
400	"	"	"	"	11,538			214	146	88	30	7.0	833
401	"	"	"	"	11,355	200	222			138	141	7.1	836
402	"	"	"	"	11,158	259	124			138	136	6.9	883
403	"	"	"	"	11,170	400	343			86	78	7.4	855
Average					11,223	286	230	232	153	122	88	7.1	845

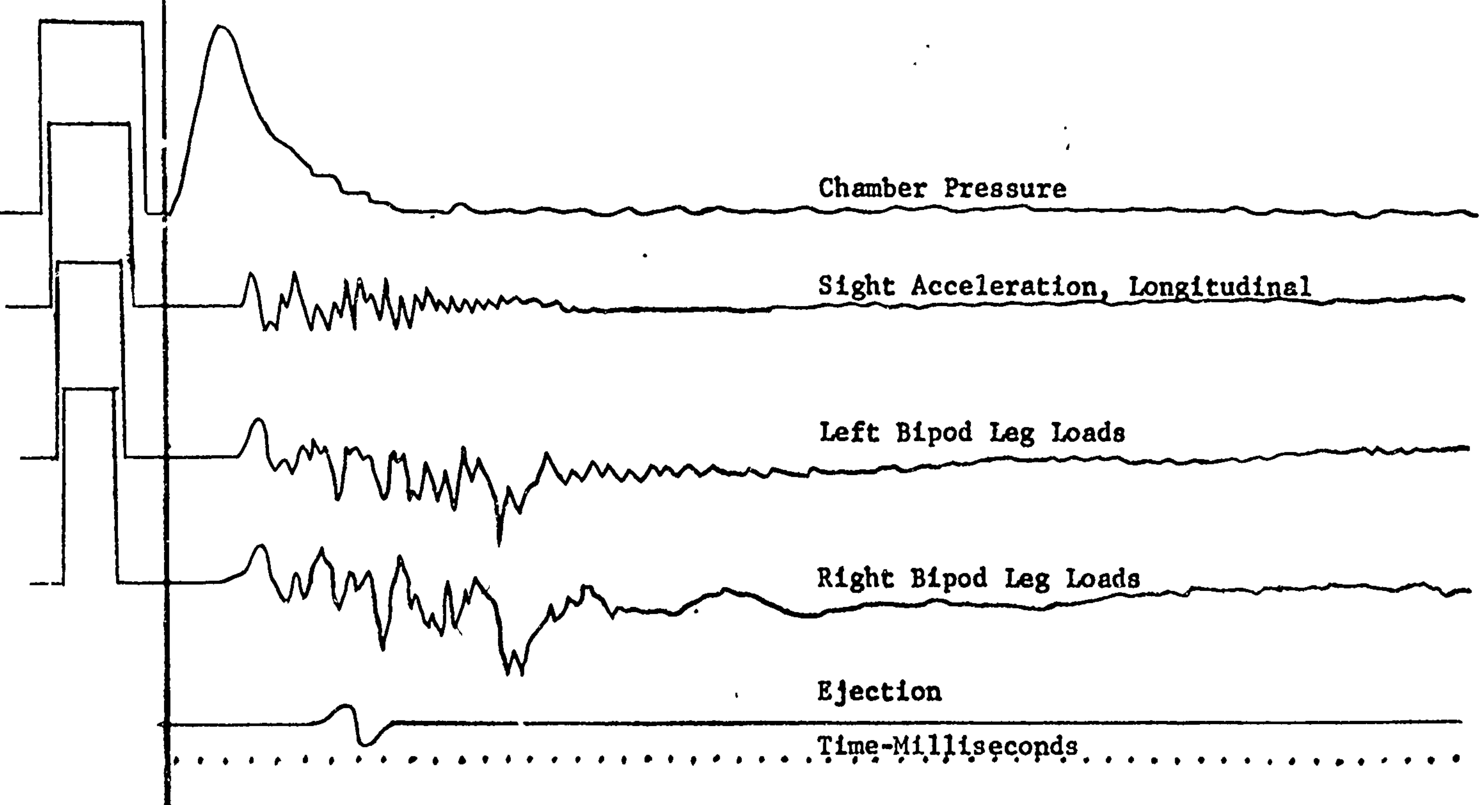


Typical Firing

M29 Zone 9 70 Degree Elevation Concrete

CP Cal. - 10,000 psi. LBL Cal. - 200 lbs.

SAL Cal. - 400 g's RBL Cal. - 200 lbs.



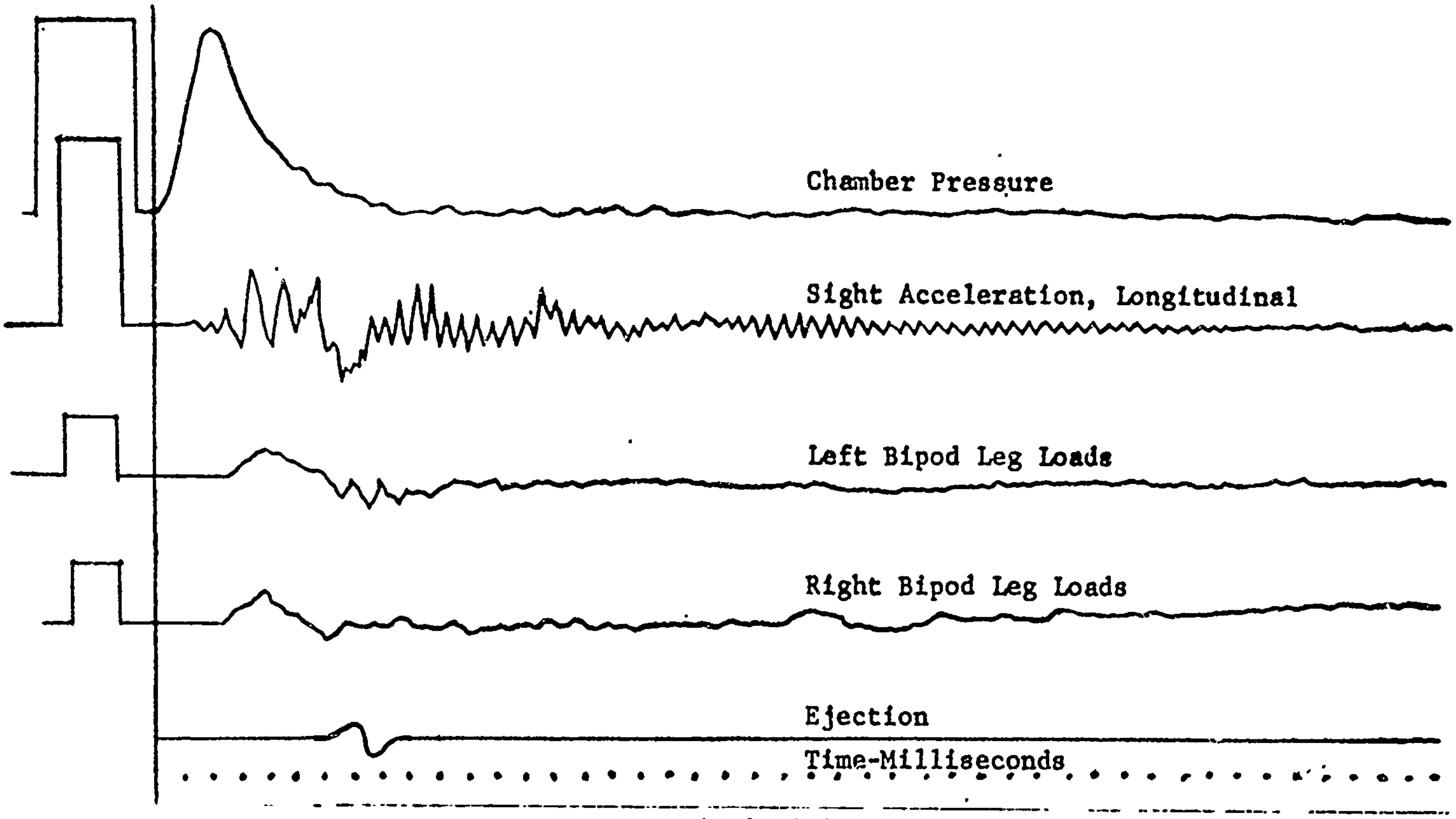
Typical Firing

T227 Zone 9 70 Degree Elevation Concrete

CP Cal. - 10,000 psi. LBL Cal. - 200 lbs.

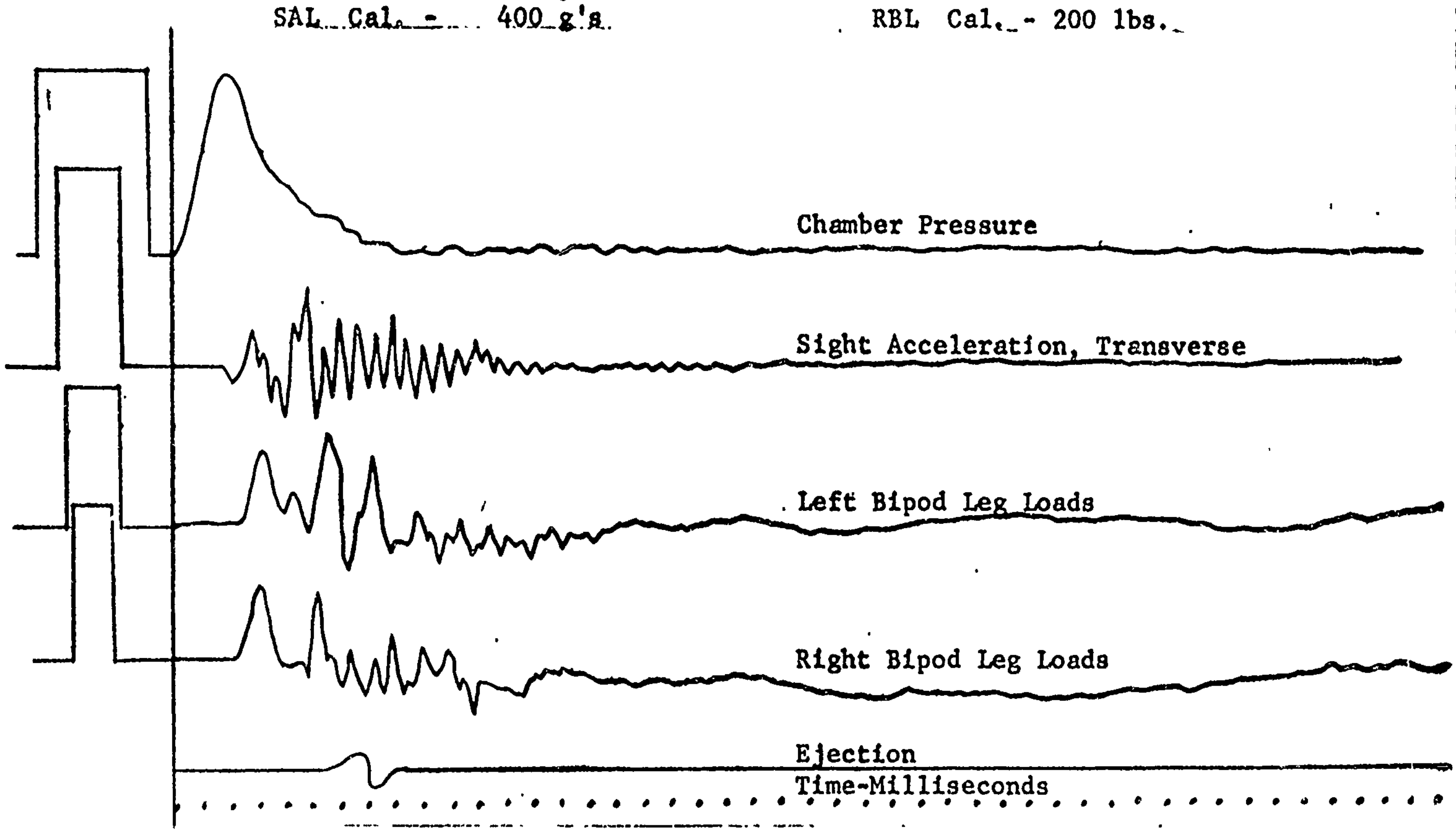
SAL Cal. = 400 g's RBL Cal. - 200 lbs.

Figure 15



Typical Firing

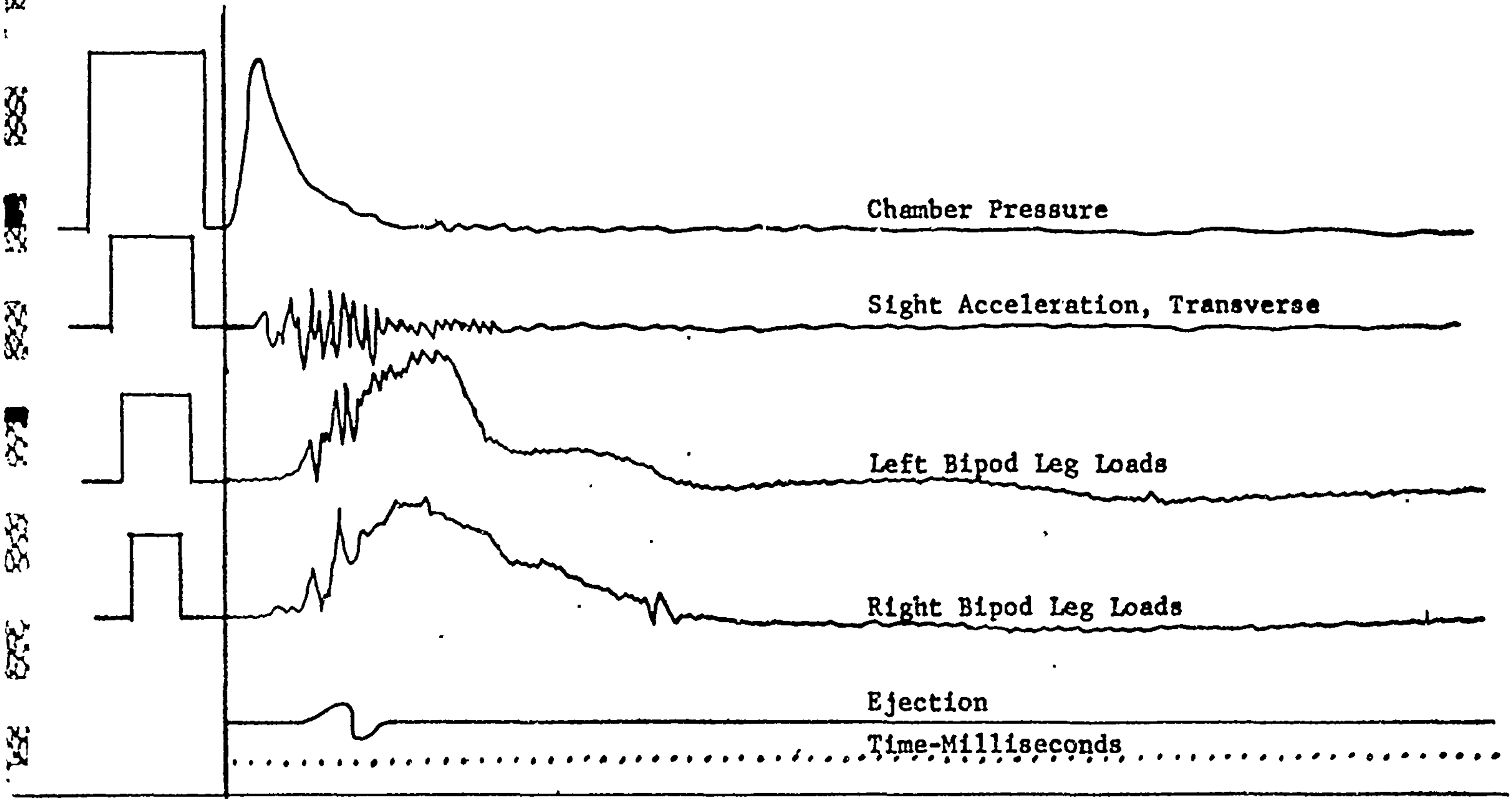
M29 Zone 9 45 Degree Elevation Concrete
CP Cal. - 10,000 psi. LBL Cal. - 200 lbs.
SAL Cal. - 400 g's RBL Cal. - 200 lbs.



Typical Firing

T227 Zone 9 45 Degree Elevation Concrete
CP Cal. - 10,000 psi. LBL Cal. - 200 lbs.
SAT Cal. - 400 g's RBL Cal. - 200 lbs.

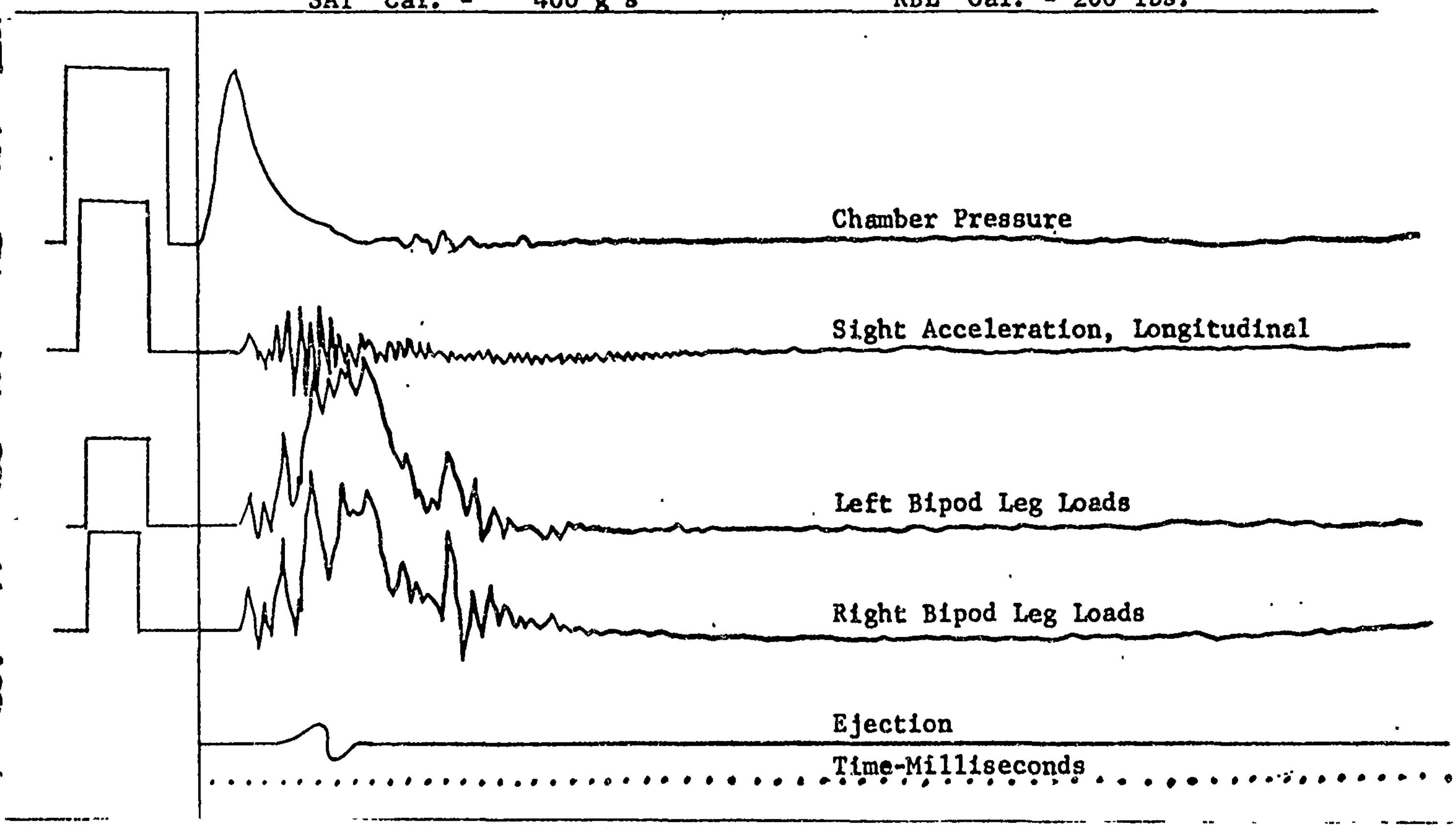
Figure 16



Typical Firing

M29 Zone 9 70 Degree Elevation Sandy Loam

CP Cal. - 10,000 psi. LBL Cal. - 200 lbs.
SAT Cal. - 400 g's RBL Cal. - 200 lbs.

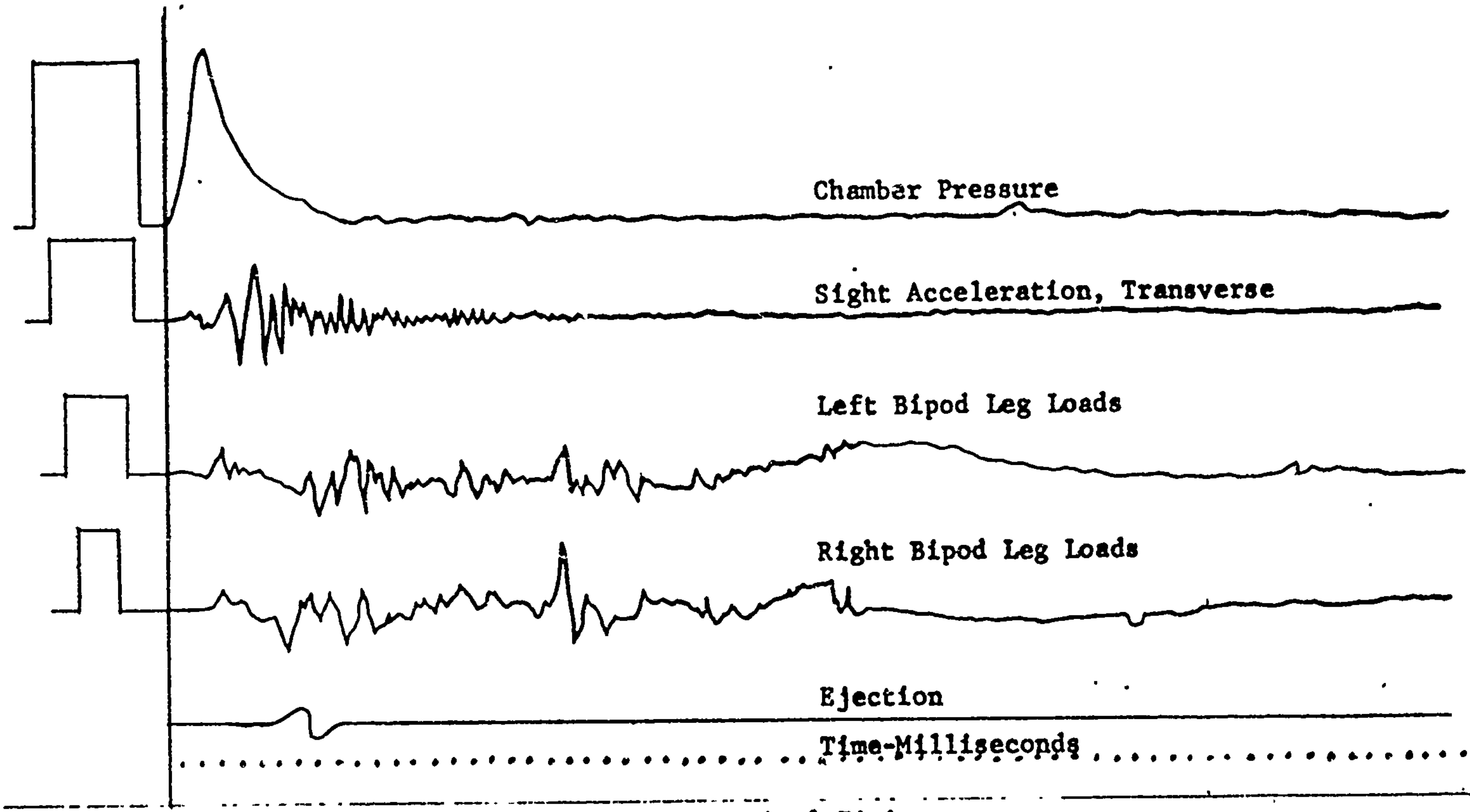


Typical Firing

T227 Zone 9 70 Degree Elevation Sandy Loam

CP Cal. - 10,000 psi. LBL Cal. - 200 lbs.
SAL Cal. - 400 g's RBL Cal. - 200 lbs.

Figure 17

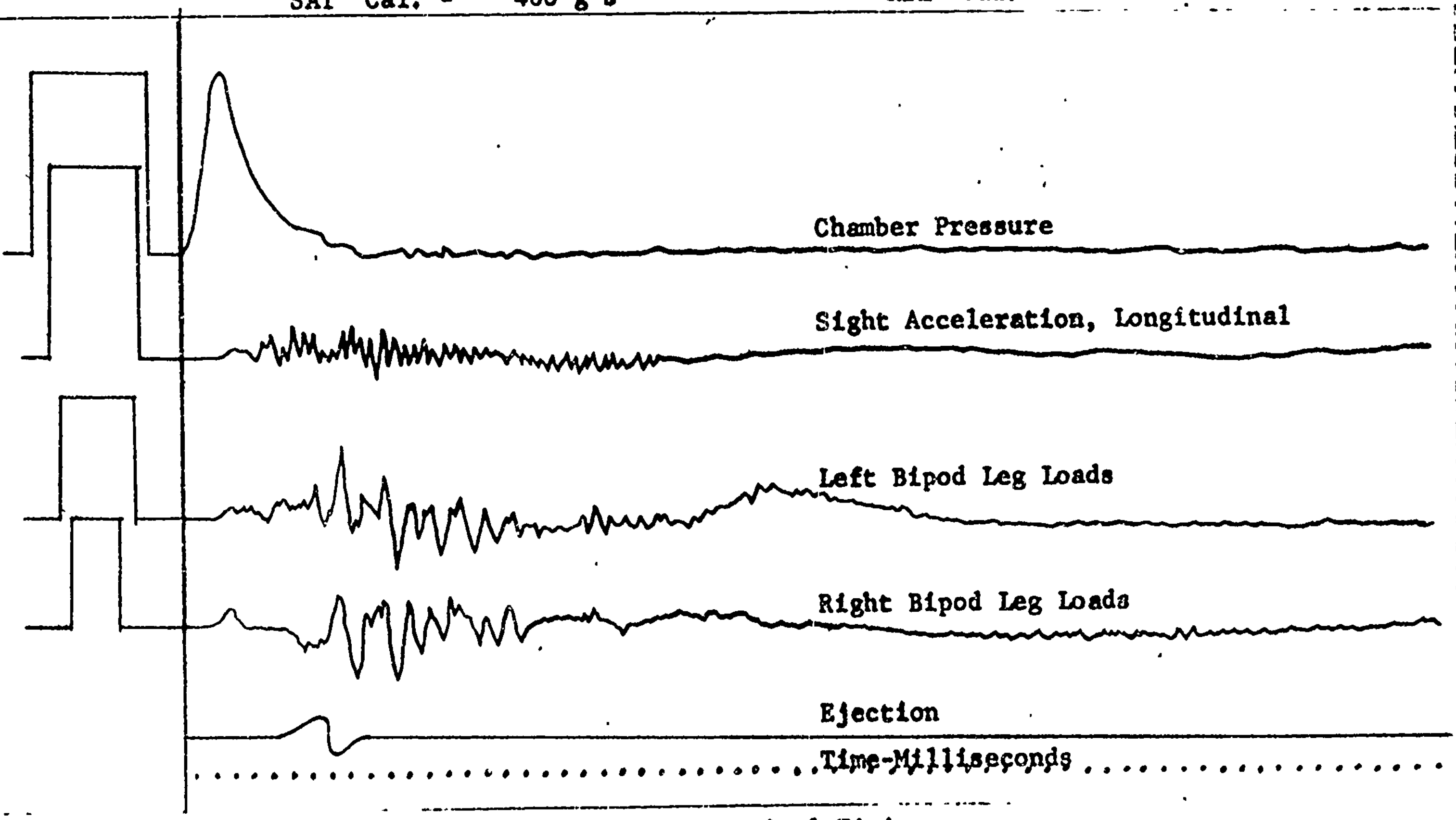


Typical Firing

M29 Zone 9 45 Degree Elevation Sandy Loam

CP Cal. - 10,000 psi. LBL Cal. - 200 lbs.

SAT Cal. - 400 g's RBL Cal. - 200 lbs.



Typical Firing

T227 Zone 9 45 Degree Elevation Sandy Loam

CP Cal. - 10,000 psi. LBL Cal. - 200 lbs.

SAL Cal. - 400 g's RBL Cal. - 200 lbs.

Figure 18

Correlation of Firing Data

Upon reduction of the firing records to numerical data, these data and the firing records were reviewed simultaneously for correlation, and to determine event significances which were not apparent from the numerical data. The data and discussion presented herein are drawn from correlation of firing data by numerical matrix.

It should be noted in comparison of these data that controlled baseplate cants are presented in all firings. No normalized series of firings were assigned as a control series for this group. Because of this, the correlations which may be made describe only the influence of these two conditions of baseplate cant with respect to each other, and to the two mortars.

Baseplate Reaction

As previously discussed, the baseplate reaction data recorded during this test group were set aside as invalid due to the gross bending of the base plugs which occurred while firing from emplacement on concrete.

Chamber Pressure

No direct correlation has been established between chamber pressure and the other controlled variables. These firings were conducted during the month of January, and during that time, ambient temperature varied from 10 to 60°F. Any variations in chamber pressure due to the influence of controlled variables are obscured by the much larger obscured day-to-day and round-to-round variations resulting from temperature, humidity, etc. A much greater sampling under more closely controlled conditions would be required to provide a basis for correlating variations in chamber pressure to other controlled variables.

Sight Accelerations, Transverse

M29 Mortar

Averaged over the entire spectrum of variables, the correlation of transverse sight accelerations to soil and elevation is as follows:

		Left Acceleration (g)	Right Acceleration (g)	Mean	Ratio Left/Right
1.	Sandy Loam	250	216	235	1.15
	Concrete	228	202	216	1.13
	Mean Ratio SL/Con.			1.09	
2.	70° Elevation	231	195	213	1.18
	45° Elevation	251	223	237	1.13
	Mean Ratio 70°/45°			0.90	

Correlated with respect to specific soil condition, the relationship becomes:

		Left Acceleration (g)	Right Acceleration (g)	Mean	Ratio Left/Right
1.	Sandy Loam 70° Elevation	258	223	240	1.16
	45° Elevation	248	210	229	1.18
	Mean Ratio 70°/45°			1.05	
	Sandy Loam, -5 B P Cant	232	207	220	1.12
	R5 B P Cant	274	225	249	1.22
	Mean Ratio -5/R5			0.88	

	Left Acceleration (g)	Right Acceleration (g)	Mean	Ratio Left/Right
2. Concrete				
70° Elevation	204	168	186	1.21
45° Elevation	254	237	245	1.07
Mean Ratio 70°/45°			0.76	
Concrete				
-5 B P Cant	203	186	195	1.09
R5 B P Cant	255	218	236	1.17
Mean Ratio -5/R5			0.82	

T227 Mortar

Averaged over the entire spectrum of variables, the correlation of transverse sight accelerations to soil and elevation is as follows:

	Left Acceleration (g)	Right Acceleration (g)	Mean	Ratio Left/Right
1. Sandy Loam	132	128	130	1.03
Concrete	198	162	180	1.22
Mean Ratio SL/Con.			0.72	
2. 70° Elevation	179	169	174	1.06
45° Elevation	151	121	136	1.25
Mean Ratio 70°/45°			1.28	

Correlated with respect to specific soil conditions, the relationship becomes:

	Left Acceleration (g)	Right Acceleration (g)	Mean	Ratio Left/Right
1. Sandy Loam				
70° Elevation	166	163	165	1.02
45° Elevation	98	92	95	1.07
Mean Ratio 70°/45°			1.60	
Sandy Loam				
-5 B P Cant	127	120	123	1.06
R5 B P Cant	122	136	130	0.90
Mean Ratio -5/R5			0.95	
2. Concrete				
70° Elevation	192	175	183	1.10
45° Elevation	204	150	177	1.36
Mean Ratio 70°/45°			1.04	
Concrete				
-5 B P Cant	194	141	167	1.38
R5 B P Cant	203	136	144	1.49
Mean Ratio -5/R5			0.99	

On the Mortar M29, the sight M34 experiences levels of transverse acceleration which are some 45% higher, when averaged over the entire spectrum of variables, than those experienced on the Mortar T227.

This is due primarily to the 'close coupling' of the sight unit to the Mount M23, by a fixed sight bracket. This close coupling permits large amplitude vibrations and acceleration-producing motions to be transmitted, with good fidelity, from the mount to the sight unit. The sight does therefore, experience all gross motions, vibrations, and mechanical shock. that are present in the mount.

The Mount T64 is equipped with a rotating sight bracket. This rotating bracket is so fabricated and mounted that the most direct coupling with the sight unit is in the transverse plane, however, some mechanical 'play' is present in the transverse plane. This mechanical play creates a loose coupling which attenuates the higher frequency vibrations and acceleration-producing motions that are transmitted from the mount to the sight unit.

<u>Sight Accelerations Longitudinal</u>

<u>M29 Mortar</u>

Averaged over the entire spectrum of variables, the correlation of longitudinal sight accelerations to soil and elevation is as follows:

		Rearward Acceleration (g)	Forward Acceleration (g)	Mean	Ratio Rwd./Fwd.
1.	Sandy Loam	210	194	202	1.08
	Concrete	179	200	189	0.89
	Mean Ratio SL/Con.			1.07	
2.	70° Elevation	177	192	184	0.92
	45° Elevation	212	202	207	1.05
	Mean Ratio 70°/45°			0.89	

Correlated with respect to specific soil condition, the relationship becomes:

	Rearward Acceleration (g)	Forward Acceleration (g)	Mean	Ratio Rwd./Fwd.
1. Sandy Loam				
70° Elevation	206	227	217	0.91
45° Elevation	215	161	188	1.33
Mean Ratio 70°/45°			1.15	
Sandy Loam				
-5 B P Cant	190	157	174	1.21
R5 B P Cant	230	231	231	0.99
Mean Ratio			0.75	
2. Concrete				
70° Elevation	148	156	152	0.95
45° Elevation	209	244	226	0.86
Mean Ratio 70°/45°			0.67	
Concrete				
-5 B P Cant	133	157	145	0.84
R5 B P Cant	225	243	234	0.93
Mean Ratio -5/R5			0.62	

T227 Mortar

Averaged over the entire spectrum of variables, the correlation of longitudinal sight accelerations to soil and elevation are as follows:

	Rearward Acceleration (g)	Forward Acceleration (g)	Mean	Ratio Rwd./Fwd.
1. Sandy Loam	91	81	86	1.13
Concrete	95	89	92	1.06
Mean Ratio SL/Con.			0.94	
2. 70° Elevation	94	86	90	1.10
45° Elevation	91	85	88	1.07
Mean Ratio 70°/45°			1.02	

Correlated with respect to specific soil condition, the relationship becomes:

	Rearward Acceleration (g)	Forward Acceleration (g)	Mean	Ratio Rwd./Fwd.
1. Sandy Loam				
70° Elevation	98	88	93	1.12
45° Elevation	84	74	79	1.14
Mean Ratio 70°/45°			1.18	
Sandy Loam				
-5 B P Cant	100	95	98	1.06
R5 B P Cant	81	67	74	1.22
Mean Ratio -5/R5			1.32	

	Rearward Acceleration (g)	Forward Acceleration (g)	Mean	Ratio Rwd./Fwd.
2. Concrete				
70° Elevation	90	83	87	1.08
45° Elevation	98	96	97	1.02
Mean Ratio 70°/45°			0.90	
Concrete				
-5 B P Cant	88	77	83	1.15
R5 B P Cant	99	102	101	0.97
Mean Ratio -5/R5			0.81	

On the Mortar M29, the Sight M34 experiences levels of longitudinal acceleration which are some 120% higher, when averaged over the entire spectrum of variables, than those experienced on the Mortar T227.

As was the case in transverse accelerations, this is due, primarily to the coupling relationship between the fixed sight bracket on the Mount M23, and rotating sight bracket on the Mount T64.

Because of backlash and play in the sight bracket gear box the sight can, and does rotate, through small arcs, during firing. This 'floating' of the sight bracket in the longitudinal plane has a large attenuating influence on the higher frequency, acceleration-producing motions being transmitted from the mount. This influence is more pronounced in the longitudinal plane than it was in the transverse plane.

Bipod Leg Loads

M29 Mortar

Averaged over the entire spectrum of variables, the correlation of bipod leg loads to soil and elevation is as follows:

	Left Leg Loads (pounds)	Right Leg Loads (pounds)	Mean	Ratio Left/Right
1. Sandy Loam	195	183	189	1.07
Concrete	125	97	111	1.29
Mean Ratio SL/Con.			1.71	
2. 70° Elevation	196	173	184	1.14
45° Elevation	124	107	115	1.16
Mean Ratio 70°/45°			1.60	

Correlated with respect to specific soil condition, the relationship becomes:

	Left Leg Loads (pounds)	Right Leg Loads (pounds)	Mean	Ratio Left/Right
1. Sandy Loam 70° Elevation	296	274	285	1.08
45° Elevation	95	91	93	1.04
Mean Ratio 70°/45°			3.07	
Sandy Loam -5 B P Cant	208	210	209	0.99
R5 B P Cant	182	156	169	1.17
Mean Ratio -5/R5			1.24	

	Left Leg Loads (pounds)	Right Leg Loads (pounds)	Mean	Ratio Left/Right
2. Concrete				
70° Elevation	96	71	84	1.35
45° Elevation	153	122	138	1.26
Mean Ratio 70°/45°			0.61	
Concrete				
-5 B P Cant	116	98	106	1.19
R5 B P Cant	133	95	114	1.40
Mean Ratio -5/R5			0.93	

T227 Mortar

Averaged over the entire spectrum of variables, the correlation of bipod leg loads to soil and elevation is as follows:

	Left Leg Loads (pounds)	Right Leg Loads (pounds)	Mean	Ratio Left/Right
1. Sandy Loam	222	170	196	1.30
Concrete	127	118	122	1.07
Mean Ratio SL/Con.			1.60	
2. 70° Elevation	222	167	193	1.33
45° Elevation	127	121	118	1.05
Mean Ratio 70°/45°			1.64	

Correlated with respect to specific soil condition, the relationship becomes:

	Left Leg Loads (pounds)	Right Leg Loads (pounds)	Mean	Ratio Left/Right
1. Sandy Loam				
70° Elevation	364	256	310	1.42
45° Elevation	81	85	83	0.95
Mean Ratio 70°/45°			3.74	
Sandy Loam				
-5 B P Cant	219	194	207	1.13
R5 B P Cant	225	146	186	1.54
Mean Ratio -5/R5			1.11	
2. Concrete				
70° Elevation	80	79	79	1.01
45° Elevation	173	157	165	1.10
Mean Ratio 70°/45°			0.48	
Concrete				
-5 B P Cant	93	81	87	1.15
R5 B P Cant	160	155	158	1.03
Mean Ratio -5/R5			0.55	

The bipod leg loads experienced in the Mount M23 are some 6% lower, when averaged over the entire spectrum of variables, than those experienced in the Mount T64.

The values presented reflect the maximum dynamic loads recorded during each firing, and are without respect to position in the firing sequence; therefore their direct application is restricted to those considerations of overall mount dynamics, stability, and integrity.

It was noted during review of the firing records that, over the entire spectrum of variables, load profiles in the Mount T64 characteristically contained fast peaking, transient components which are much more pronounced than those in the Mount M23. Their prominence is particularly evident in those firings conducted from emplacements on concrete. Such profiles are generally associated with whipping of the bipod legs and/or bounce and jump of the mount.

Subsequently, a detailed inspection of the Mount T64 was made in an effort to determine whether these fast peaking, transient loads could be related to functional characteristics of the mount, or were inherent to the mount structure and/or configuration. During this inspection it was discovered that appreciable 'play' existed in the elevation spindle and gearbox mechanism. This play permitted the elevation spindle to move, unchecked by the elevation gears, for distances up to 0.120 inch.

The elevation spindle supports the mount yoke and barrel. Therefore it responds to and transmits weight and load components of these respective members to the bipod legs. The large degree of freedom of the elevation spindle to jump and bounce within the housing and gearbox during firing, and the loads which are attendant with such motions readily account for the fast peaking, transient loads which were detected in the bipod legs of the Mount T64.

Ejection Time

No direct correlation has been established between variances in ejection time with the controlled variables.

Muzzle Velocity

Averaged over the entire spectrum of variables no pronounced differences in muzzle velocity, between the M29 and T227 Mortars, were observed.

No correlations have been established between variances in muzzle velocity with the controlled variables. As in the case of chamber pressure any variances in muzzle velocity due to the controlled variables is obscured by the much greater day-to-day and round-to-round variations due to ambient temperature, humidity, etc.

CONCLUSIONS AND RECOMMENDATIONS

Instrumentation

As previously discussed, measurements and determinations of the patterns of motion which occur at the muzzle, while the projectile is in residence in the bore, are the most singularly significant measurements to be made in the investigation of accuracy and/or dynamic instability in mortar systems. These motions reflect the combined dynamic-influence of all the components of the weapon system, and, in turn, should provide a quantitative and comprehensive basis for evaluating the combined influence of these several factors on weapon accuracy and dynamic stability.

During the initial program studies of potential approaches and techniques, and again during a subsequent search for alternate or backup approaches, the only approach which seemed to hold promise of satisfying the requirements of this task was use of accelerometers. Firings for evaluation of piezo accelerometer systems and subsequent laboratory testing determined that, due to the discrepant performance of piezo accelerometer systems in the environment which is present on the mortar barrels, they were not suitable for this task.

The available unbonded wire accelerometers used during this study had a high range of ±1,000g and continually failed in the high-level tri-axial acceleration environment. Subsequent to termination of test operations, two ±3,000g accelerometers were received. The lead time required to obtain these accelerometers was approximately three months. During additional discussion with Statham Instruments it had been determined that special ruggedized accelerometers in the ±5,000g range could be made available within three months. It is felt that these ruggedized accelerometers might well withstand the severe environment present at the muzzle.

During review of the accelerometer traces, and in attempts to obtain meaningful indications of the patterns of muzzle motion versus time, it was concluded that a simple comparison of acceleration amplitudes, or even the graphical integration of the acceleration values to provide direction and velocity data, did not provide a sound basis for determining actual patterns of muzzle motion versus time.

Acceleration records for test firings 27, 28, and 29 were reduced to show muzzle displacement, from the original aiming point, at ejection. (See page 38). Reduction of the individual acceleration traces to displacement-versus-time values was a very time-consuming process, requiring on the order of 4 man hours to reduce each accelerometer trace, and due to this time factor only those test firings noted above were completed.

Attempts to translate the displacement-versus-time values of the two traces into polar vectors for determining patterns of muzzle motion in two planes perpendicular to the bore axis were prohibitively time consuming, and the cumulative error associated with this approach precluded the placing of any real confidence in the validity of the final numbers.

One possible approach to determining the patterns of motion at the muzzle versus time would be based upon the use of ruggedized unbonded wire accelerometers and analog integrating amplifiers for electronic translation of the acceleration profiles directly into displacement values, which in turn would be presented as a polar display on the face of a cathode ray oscilloscope. The block diagram for such a system is shown in Figure 19.

In this system the accelerometers would be mounted at the muzzle in such a manner that they monitored acceleration profiles which occurred in two planes perpendicular to the bore axis and rotated 90 degrees with respect to each other. The output from the two accelerometers would be filtered to provide a bandwidth on the order of 10-1,000 cps. This signal would then be programmed through a bank of analog integrating amplifiers which would translate the acceleration profiles directly into displacement values. Module plug-in type computing amplifiers which are suitable for this application are available from a number of manufacturers, including George A. Philbrick Inc., of Boston, Massachusetts. The output from these computing amplifiers would then be used to drive equalized vertical and horizontal deflection plates of a cathode ray

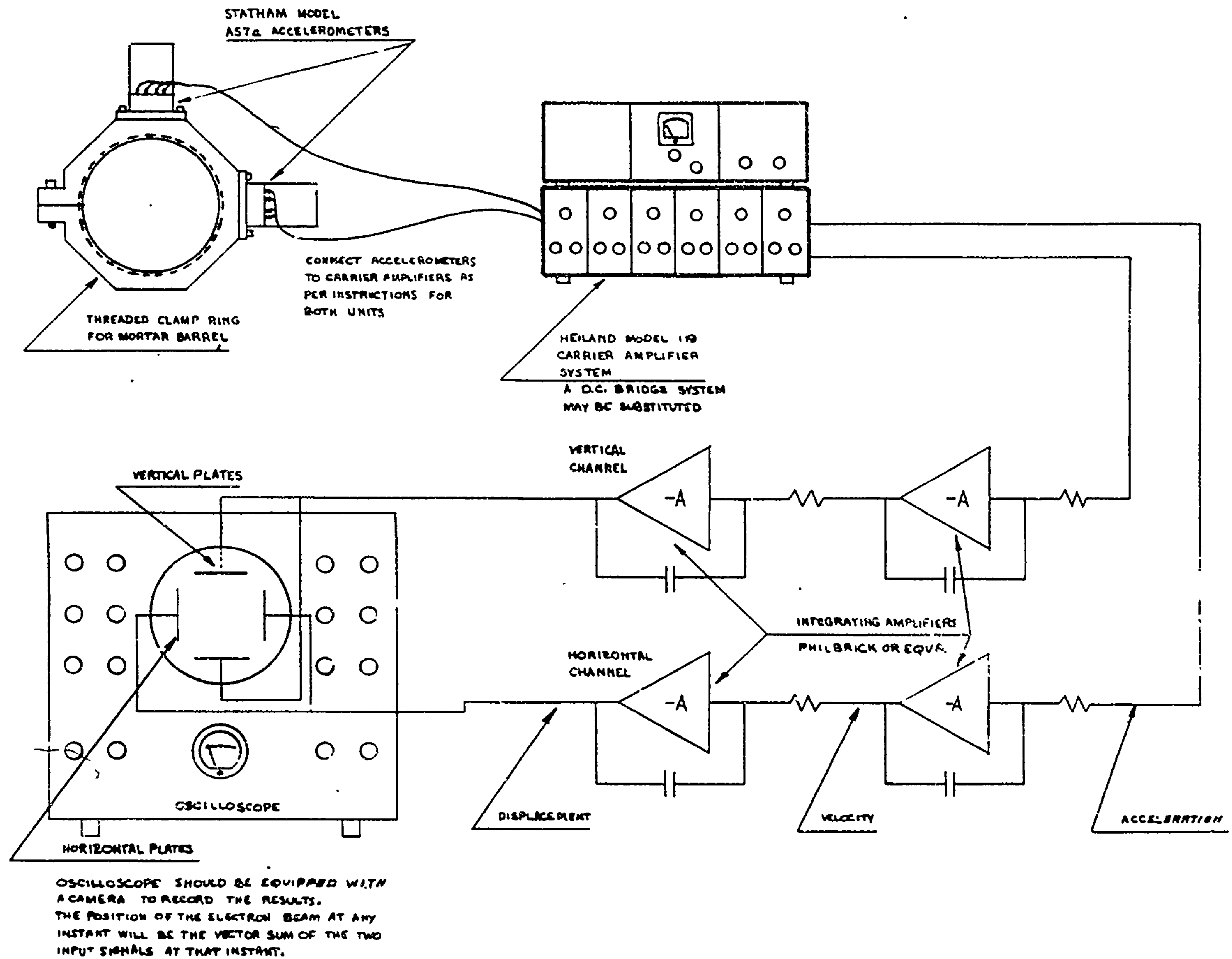


Figure 19. Suggested Muzzle Motion Instrumentation.

oscilloscope. In a polar display so presented, the "pip" of the oscilloscope would represent the centerline of the bore axis and in its excursions during the firing sequence would directly reflect the pattern of motion of the muzzle during a firing sequence. A time base could be imposed on this trace by means of cathode blanking, while the ejection event could be indicated by application of a brightening pulse to the cathode circuit. A polar display so presented on the oscilloscope could be recorded by a polaroid or other suitable still type oscilloscope camera.

In view of the need for continued development and advancement of the state of the arts of mortar weaponry, and of the need for development of a sufficiently comprehensive method for evaluation of the accuracy and/or dynamic stability factors of mortar performance, it is suggested that study and effort be continued toward development and perfection of a system for accurately measuring the motions which occur at the muzzle during the firing sequence. The ultimate value of such an experimental tool would amply justify the effort expended toward its development.

<u>Mortar Systems</u>

After review of the firing records, data, and the observations made during this test program, and despite the fact that the majority of the originally planned test firings were not completed, it is felt that several significant conclusions and observations may be made regarding the Mortar Systems M29 and T227.

In the discussions which follow, an attempt will be made to treat each major system component separately, and, if applicable, compare the relative merits of each system.

1. <u>Baseplates</u>.- The Canadian Forged Aluminum baseplate was the only baseplate used during the firing program; therefore, no comparison may be made regarding baseplate configurations or types.

It is generally concluded that, of all the major system components, the baseplate may well be the greatest singly influencing factor on dynamic stability and over-all dynamic performance of the mortar system.

During the firing sequence large recoil loads are delivered to the baseplate by the barrel. Under these large loads the baseplate experiences gross motions of two types: (1) structural flexing of the baseplate proper; and (2) excursion of the entire baseplate as it seats progressively deeper into the soil and/or skids rearward under the recoil loads. The direction and magnitude of these motions is a function of several factors, including: zone charge, elevation, soil condition, and baseplate cant angle. These gross motions of the baseplate have both a direct and indirect influence on the dynamic performance of other components in the system.

Directly: the baseplate is mechanically coupled to the barrel and acts the rear point of support for the barrel, therefore, motions of the baseplate, as described above, permit and/or cause corresponding motions of the barrel. Review of high speed film and recoil acceleration records (Figure 9) show that gross recoil motions of the baseplate and barrel occur early in the firing sequence and prior to the ejection event. Muzzle acceleration records (Figures 8 and 14) show that major muzzle motions, in planes perpendicular to the bore axis, occur prior to the ejection event.

The adverse influence of these motions would be minimal if these combined motions of the baseplate and barrel occurred only in a plane concentric with and parallel to the bore axis. Such is not the case, and due to assymetries which are present in the system, these motions are reflected as displacement of the bore axis from its original aiming point prior to shot ejection. Muzzle acceleration records for test firings 27, 28, and 29 were reduced to show muzzle displacement, from the original aiming point, at ejection (see page 38). The resultant values indicate displacement of the bore axis, by approximately 1/2 degree, prior to shot ejection. The influence of this condition on absolute weapon accuracy is obvious. In addition, these excursions of the rear point of support for the barrel result in a round-to-round modification of the original firing geometry and are the principal factors which dictate the need for, and frequency of, relay of the weapon during actual firing.

Indirectly: these excursions of the rear point of support for the barrel (the baseplate) under recoil loads permit and/or cause assymetric motion of the barrel which, in turn, induces significant levels of load into the mount. If these loads are not distributed symetrically to the bipod legs or, if the mount is dynamically unstable under load, the mount may actually have the effect of amplifying the original assymetries which were permitted and/or caused by baseplate motion.

The magnitude of the influence of the baseplate on other component dynamics and, in turn, on over-all system dynamic behavior is clearly demonstrated in Test Group 3 where, introduction of a controlled +5 degree right transverse baseplate cant (i.e., depression of the left edge of the baseplate 5 degrees) caused a marked increase in the magnitude of differential transverse sight accelerations with a pronounced trend toward greater sight accelerations to the left. In addition, the introduction of this controlled baseplate cant caused a similar increase in differential bipod leg loads, with a pronounced tendency toward greater loads in the left leg. This occurred in both the M29 and T227 mortars.

In view of the pronounced influence of the baseplate on other component dynamics, and indeed on the over-all dynamic behavior of the mortar system, it is recommended that design requirements and considerations for future baseplates reflect emphasis accordingly.

2. <u>Barrels</u>.- As previously noted and during the firing of Test Group 3, the base plugs on both the M29 and T227 barrel were permanently deformed while firing from emplacements on concrete, thus indicating that the structural integrity of both base plugs, under those firing conditions is, at best, marginal.

If tactical considerations dictate the requirement for these systems to withstand sustained firing from 'hard' emplacements, only two alternative approaches are immediately apparent: (1) directly increase the mechanical strength of the base plugs by providing greater load bearing cross sections, or (2) incorporation of a light-weight, short-stroke recoil system into the medium mortar system.

It is recommended that the second alternative be pursued and that a light-weight, short-stroke recoil system be developed for the medium mortars. Such a recoil system would significantly reduce the height of the maximum recoil load profiles and lessen the load bearing and strength (thus, weight) requirements for all the associated components, i.e., barrel, base plug, baseplate and weapon carrier mount. In addition, reduction of the maximum recoil load delivered to the baseplate will result in a corresponding reduction in assymetric motions of the baseplate which result from these loads and, thus, enhance the dynamic behavior of the entire mortar system.

Except for the deformation of the base plugs which occurred during firing from emplacements on concrete, both the M29 and T227 barrels performed satisfactorily during these tests.

The scope of this contract did not include the evaluation of the M29 and T227 barrels at sustained high rates of fire and attendant elevated temperatures; therefore, no comparison may be made regarding their relative performance under these conditions.

3. Mounts.- In both the M29 and T227 Mortars the sight accelerations to the left were of greater amplitude than those to the right, and the loads in the left bipod leg were of greater magnitude than those in the right leg, when the mortar was at center traverse.

Over the entire spectrum of firing variables, the T227 Mortar system consistently experienced muzzle accelerations which were significantly greater than those experienced on the M29 under the same conditions. At the same time, bipod leg loads on the T227 Mortar were somewhat greater than those experienced on the M29 under the same conditions. As previously discussed and upon inspection of the T64 Mount, it was determined that considerable play existed between the elevation spindle, its housing and gearbox. It was concluded that this play might well account for the fast-peaking transient loads which occurred in the bipod legs of the T64 Mount, and thus might account for the generally higher peak loads. It is also possible that this jump and bounce might account for the generally higher muzzle accelerations in the T227 Mortar system although sufficient correlation of data was not obtained to directly support such a conclusion.

During the firings from emplacements on concrete, the T227 Barrel Ring, which connects the barrel to the shock absorber, consistently failed after a series of firings. This failure was characterized by rearward bending of the projecting lug which is pinned to the shock absorber rod. Investigation of these failures disclosed that the shock absorber on the T64 Mount does not provide adequate shock absorbing action in short counter-recoil strokes (0-1 inch). Under these conditions and with the high levels of counter-recoil energy attendant with bounce of the barrel when firing from concrete, the full brunt of the counter-recoil forces were transmitted directly to the lug causing bending and subsequent failure of the part. This problem was not encountered in the shock absorber on the M23 Mount.

It is recommended that the T64 shock absorber be re-designed and/or modified to provide the required short-stroke shock absorbing performance.

During firings from sandy loam the flange on the T64 Mount which supports the rotating sight bracket failed, permitting the entire rotating sight bracket assembly to fall away. This failure was a structural failure, characterized by fracture of the web of material between the diameter of the sight bracket recess and the edge of the mounting flange.

It is recommended that this mounting flange be strengthened to provide the required structural integrity.

Over the entire spectrum of firing variables it was noted that the rotating sight bracket on the T64 Mount, because of the acceleration loads in the sight, and because of the attendant mechanical loads, moved through small arcs during firing and subsequently came to rest in a position that was 'canted' with respect to its original lay. This motion of the rotating sight bracket occurs because of play which exists in the rotating gear mechanism and because of the low gear ratio in the driving gears.

It is recommended that the rotating gear mechanism be 'tightened up' to eliminate play in the system, and that a high gear ratio be incorporated into the driving gears to provide greater resistance to rotation of the sight bracket under motion induced loads, and to provide the gunner with a less coarse cant correcting control.

During the entire test series it was noted that the M34 Sight frequently 'jumped out' of the sight brackets on both the M29 and T227 Mortars. This is obviously due to the need for a more positive locking system to eliminate the danger of damage to the sight due to 'jump out'.

Two instances of failure of the cast alloy elevation handle on the T64 Mount were recorded during the test program. These were structural failures and are attributed to the low resistance of this material to mechanical loads that are encountered during rough handling. In both instances these handles were broken by inadvertent striking of the handle by the barrel while shifting the mortars between emplacements. Failure of such a part in the field would seriously penalize the weapon performance to the point of rendering it ineffective in the performance of its mission.

It is recommended that these parts, and other critical components, be designed and fabricated to provide the greatest amount of resistance to breakage, and rough handling which may be encountered in the field.

FINAL CONCLUSIONS AND RECOMMENDATIONS

It should be noted these mortar systems were tested and evaluated in an 'as provided' state, and no attempts were made to make corrective changes to any system or component, or to evaluate or predict the performance of any system or component in which corrective changes might be made. It is in view of these facts that the general conclusions drawn from this test program are made.

Upon review of the firing records and data obtained during the course of this test program, and of the discussion and conclusions contained above, it must be concluded that: In its present state, and without additional and extensive improvement and/or modification the Mortar System T227 is, in its dynamic behavior, over-all performance and structural integrity, an inferior system when compared with the Mortar System M29.

In view of the prominent position of modern mortar systems in the over-all tactics and strategies of conventional and limited warfare, the need to provide the user with the best weapon systems available within current state of the arts, and the need to push forward the state of the arts of mortar weaponry, it is recommended that continued effort be expended to provide the experimental tools necessary to fully evaluate the significant elements of mortar performance, and to translate these into design criteria and information for the design of new and improved medium mortar systems.

APPENDIX

Operational specifications and objectives, variables, and events of the seven test firing groups are included here for reference.

OPERATIONAL SPECIFICATIONS

This test program involves the evaluation of material over a spectrum of firing conditions which encompasses more than 150 variables. It is, therefore, essential that these variables be controlled so that the data obtained shall be valid and free of the effects of undesirable variables.

It is to this end that the following operational specifications are set forth:

1. Emplacement

Concrete

a. Segments of concrete will be excavated to receive the baseplate spades and bipod feet.

b. The weapon will then be positioned in these excavations in accordance with the firing specifications.

c. The baseplate will be securely sandbagged to prevent displacement of the spades from the excavations or rearward motion of the baseplate.

d. The bipod legs will be sandbagged to prevent displacement of the feet from the excavations.

Sandy Loam and Firm Turf

a. The weapon will be positioned at the selected site and elevated to fire at a high angle.

b. Two rounds with zone 8 charges will be employed to seat the baseplate. The baseplate will then be levelled to firing specifications.

c. The bipod feet will be positioned according to firing specifications and seated well.

2. <u>Firing</u>

a. The baseplate will, at all times be positioned so that the spades describe an 'X' across the axis of the barrel and that the center lines of the spades intersect this barrel axis at 45 degrees.

b. Baseplate cant during non-cant firings shall be maintained within ± 2½ degrees from the horizontal in any plane.

c. Baseplate cant during canted firings shall be maintained at 5 degrees +3 degrees and -0 degrees in the specified plane.

d. The baseplate will be taken up and reseated whenever it has become dug in beyond a practical limit.

e. The bipod feet position will be maintained at 24 ± 2 inches forward of the baseplate except as necessary to achieve a 45 degree elevation. During these firings, the legs will be positioned forward only as necessary to reach the 45 degree elevation with the elevation spindle extended not more than 1½ inches.

f. Elevation tolerance ± ½ degree.

g. Traverse tolerance ± ½ degree.

h. Point of support, M29 barrel, 14 inches (center of yoke to muzzle).

i. Point of support, T227E2 barrel, 16 inches for all firings except those deviations specified in the point of support test group.

j. ALL FIRINGS TO BE CONDUCTED WITH THE BARREL AXIS AIMED ALONG A MAGNETIC HEADING OF 60 ± 10 DEGREES.

TEST GROUP 1

648 Rounds-M362

Objective

The objective of this test group is to investigate the performance parameters of the basic mortar systems M29 and T227E2, employing the Round, H.E., M362, over a spectrum of 108 variables and to collect a basic body of performance data to which subsequent tests, which embody additional variables, may be correlated.

Variables	1	2	3
Base Plates	M23A3	M23A3	--------
Mounts	M23A3	T64E2	--------
Tubes	M29	T227E2	--------
Zones	6	8	9
Elev.	45 deg.	55 deg.	70 deg.
Trav.	Center	Ex. Left	--------
Soil	Concrete	S. Loam	F. Turf

Events	Action
Base Plate Reaction	Monitor throughout test group.
Chamber Pressure	Monitor throughout test group.
Bipod Leg 1.	--------
Bipod Leg 2.	--------
Muzzle Acc. 1.	Alternate at discretion with Spec. 1.
Muzzle Acc. 2.	Alternate at discretion with Spec. 2.
Shot Ejection	Monitor throughout test group.
Muzzle Velocity	Monitor throughout test group.
High Speed Camera	Intermittent, at discretion.
Sighting Board	Intermittent, at discretion.
Special 1.	Acc. near base of tube-Note 1.
Special 2.	Acc. near base of tube-Note 1.

Notes

1. Muzzle accelerometers will, at discretion, be alternately positioned near base of tube to investigate accelerations experienced in this area, under various firing conditions. The location which evidences greatest accelerations will be monitored most heavily.

TEST GROUP 2

96 Rounds-M362

Objective

The objective of this test group is to investigate unsymmetrical loading of the bipod legs and/or possible dynamic instabilities resulting from installation of the Sight, M34A2 at its present mounting point.

Variables	1	2	3
Base Plates	M23A3	M23A3	--------
Mounts	M23A3	T64E2	--------
Tubes	M29	T227E2	--------
Zones	9	------	--------
Elev.	55 deg.	70 deg.	--------
Trav.	Ex. Left	------	--------
Soil	Concrete	S. Loam	--------
Sight, M34A2	Off	In Place	--------

Events	Action
Base Plate Reaction	--------
Chamber Pressure	Monitor throughout test group.
Bipod Leg 1.	Monitor throughout test group.
Bipod Leg 2.	Monitor throughout test group.
Muzzle Acc. 1.	Monitor throughout test group.
Muzzle Acc. 2.	Monitor throughout test group.
Shot Ejection	Monitor throughout test group.
Muzzle Velocity	Monitor throughout test group.
High Speed Camera	Intermittent, at discretion.
Sighting Board	Intermittent, at discretion.

TEST GROUP 3

192 Rounds-M362

Objective

The objective of this test group is to investigate unsymmetrical loading of the bipod legs and/or possible dynamic instabilities resulting from various conditions of base plate cant, and further to investigate the direction and magnitude of accelerations experienced at the sight mounting point under these same conditions.

Variables	1	2	3
Base Plates	M23A3	M23A3	------
Mounts	M23A3	T64E2	------
Tubes	M29	T227E2	------
Zones	8	9	------
Elev.	45deg.	70deg.	------
Trav.	Center	------	------
Soil	Concrete	S. Loam	------
Base Plate Cant	5deg. Left	5deg. Forward	------

Events	Action
Base Plate Reaction	Monitor throughout test group.
Chamber Pressure	Monitor throughout test group.
Bipod Leg 1.	Monitor throughout test group.
Bipod Leg 2.	Monitor throughout test group.
Muzzle Acc. 1.	-------
Muzzle Acc. 2.	-------
Shot Ejection	Monitor throughout test group.
Muzzle Velocity	Monitor throughout test group.
High Speed Camera	Intermittent, at discretion.
Sighting board	Intermittent, at discretion.
Special 1.	Sight mount acc.-Note 1.
Special 2.	-------

Notes

1. Accelerometer to be mounted at sight mounting point and alternated in orientation to determine direction and magnitude of accelerations experienced by the Sight, M34A2 when mounted in this location.

TEST GROUP 4

96 Rounds-M362

Objective

The objective of this test group is to investigate the effect of shifting the point of bipod support along the barrel on muzzle motion and resulting force on the bipod.

Variables	1	2	3
Base Plates	M23A3	------	------
Mounts	Special	------	------
Tubes	T227E2	------	------
Zones	6	8	------
Elev.	45deg.	70deg.	------
Trav.	Center	------	------
Soil	Concrete	S. Loam	------
Support Points	16in.Note-1	20in.Note-1	------

Events	Action
Base Plate Reaction	------
Chamber Pressure	Monitor throughout test group.
Bipod Leg 1.	Monitor throughout test group.
Bipod Leg 2.	Monitor throughout test group.
Muzzle Acc. 1.	Monitor throughout test group.
Muzzle Acc. 2.	Monitor throughout test group.
Shot Ejection	Monitor throughout test group.
Muzzle Velocity	Monitor throughout test group.
High Speed Camera	Intermittent, at discretion.
Sighting Board	Intermittent, at discretion.

Notes

1. Distance to be measured from the center of the mount yoke to the muzzle.

TEST GROUP 5

192 Rounds-M362

Objective

The objective of this test group is to investigate the effect of replacing a standard barrel assembly with one having an eccentric basecap so that the center of reaction is displaced from the axis of the mortar barrel, and further to investigate the effect of base plate cant upon such a firing geometry.

Variables	1	2	3
Base Plates	M23A3	------	------
Mounts	T64E2	------	------
Tubes	Special	------	------
Zones	8	9	------
Elev.	45deg.	70deg.	------
Trav.	Center	------	------
Soil	Concrete	S. Loam	------
Base Plate Cant	Center	5deg. Left	------
Ecc. Base Plug	Up	Down	------

Events	Action
Base Plate Reaction	------
Chamber Pressure	Monitor throughout test group.
Bipod Leg 1.	Monitor throughout test group.
Bipod Leg 2.	Monitor throughout test group.
Muzzle Acc. 1.	Monitor throughout test group.
Muzzle Acc. 2.	Monitor throughout test group.
Shot Ejection	Monitor throughout test group.
Muzzle Velocity	Monitor througnout test group.
High Speed Camera	Intermittent, at discretion.
Sighting Board	Intermittent, at discretion.

TEST GROUP 6

96 Rounds-M42A1

Objective

The objective of this test group is to investigate the performance parameters of the basic mortar systems M29 and T227E2, employing the Round H. E., M43A1, over a spectrum of 24 variables in such a manner that the performance may be directly compared with that of the respective systems when the Round, H. E., M362 is employed.

Variables	1	2	3
Base Plates	M23A3	M23A3	------
Mounts	M23A3	T64E2	------
Tubes	M29	T227E2	------
Zones	8	11	------
Elev.	45deg.	70deg.	------
Trav.	Note-2	------	------
Soil	Concrete	S. Loam	P. Turf

Events	Action
Base Plate Reaction	Monitor throughout test group.
Chamber Pressure	Monitor throughout test group.
Bipod Leg 1.	------
Bipod Leg 2.	------
Muzzle Acc. 1.	Monitor throughout test group.
Muzzle Acc. 2.	Monitor throughout test group.
Shot Ejection	Monitor throughout test group.
Muzzle Velocity	Monitor throughout test group.
High Speed Camera	Intermittent, at discretion.
Sighting Board	Intermittent, at discretion.

Notes

1. This group will not be fired as a separate group, but will be integrated with Test Group 1. Two rounds will be fired at each variable condition.

2. The traverse setting to be employed for these firings will be that setting which evidences greatest effect on muzzle acceleration as determined in Test Group 1.

TEST GROUP 7

64 Rounds-M362

Objective

The objective of this test group is to generate experimental data on patterns of acceleration at the mount in support of the study of center of gravity changes in the mount during firing.

Variables	1	2	3
Base Plates	M23A3	M23A3	------
Mounts	M23A3	T64E2	------
Tubes	M29	T227E2	------
Zones	6	8	------
Elev.	45deg.	70deg.	------
Trav.	Center	Ex. Left	------
Soil	Concrete	S. Loam	------

Events	Action
Base Plate Reaction	--------
Chamber Pressure	Monitor throughout test group.
Bipod Leg 1.	--------
Bipod Leg 2.	--------
Muzzle Acc. 1.	--------
Muzzle Acc. 2.	--------
Shot Ejection	Monitor throughout test group.
Muzzle Velocity	Monitor throughout test group.
High Speed Camera	--------
Sighting Board	--------
Special 1.	Acc. near elevation spindle on mount.-Note 1.
Special 2.	Acc. near elevation spindle on mount.-Note 1.

Notes

1. The prime objective of this group is to provide experimental data for the study of center of gravity change in the mount during firing. This will be accomplished by accelerometers mounted near the elevation gear box on the mount. These events will be monitored throughout the test group. The uncommitted information channels may be used to investigate additional areas of interest that may develop as the firing program progresses.